ALCOA

ALCOA STRUCTURAL HANDBOOK

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ALCOA

STRUCTURAL HANDBOOK

A DESIGN MANUAL FOR ALUMINUM

ALUMINUM COMPANY OF AMERICA

PITTSBURGH, PENNSYLVANIA

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Specifications for Structures of Aluminum Alloy 6061-T6
Specifications for Structures of Aluminum Alloy 2014-T6

NOTICE

Some of the materials or their uses, the alloys or their processes of fabrication or casting, their heat treatment or the products of one or more of these operations mentioned in this handbook are covered by United States patents.

Foreword

The diversity of form, characteristics and uses of aluminum alloy products emphasizes the need for a broad approach to the design of aluminum alloy strength members. This revised edition of the ALCOA STRUCTURAL HANDBOOK presents such an approach. The information is presented by means of formulas, discussion, examples and tables, and is based on laboratory investigations, analytical studies, field tests and extensive practical experience.

Recent improvements in Alcoa aluminum alloy products, together with advances in design methods, are reflected in the revision of all sections of the handbook.

The calculations involved in the preparation of this book are based upon the nominal cross sections as shown in the tables. It should be noted, however, that in practice these sections vary according to the commercial tolerances shown in the tables. The principal mechanical property tables list minimum properties rather than typical properties. These mechanical properties are given in units of kips per square inch (1 kip=1,000 lb).

The services of the research and development facilities of Aluminum Company of America are available to customers who desire assistance in the application of aluminum to their products. Recommendations on alloy, temper, product, design and fabrication are furnished without cost.

Aluminum Company of America assumes responsibility for the quality of its products but does not assume responsibility for customers' designs or for the performance of structures or parts made in accordance therewith.

The extent of responsibility assumed by Aluminum Company of America is set forth in detail in the Company's formal warranty clause, which appears on all acknowledgments of its orders and which is quoted in full on page 335 of this book.

CHARACTERISTICS, MANUFACTURE AND FABRICATION OF ALUMINUM ALLOY PRODUCTS

Characteristics, Manufacture and Fabrication of Aluminum Alloy Products

Aluminum alloys find a place in structures for two principal reasons. First, the use of aluminum results in a considerable reduction in weight with no loss of strength; second, aluminum structures require a minimum of maintenance. Aluminum alloys offer a further advantage in their ease of fabrication. Any well-equipped shop can use aluminum with no major change of methods or equipment.

Structural products are available commercially in a variety of aluminum alloys and in forms adapted to a wide range of use. The alloys commonly used are given in Tables 1a and 1b, pages 26 to 32.

From the mining of the ore to final inspection, each step in the manufacture of Alcoa® aluminum alloy products is under accurate control. This control, combined with rigid testing routine for all products, insures uniform quality of the materials produced by Aluminum Company of America. The production, metallurgy, fabrication and testing of Alcoa aluminum and its alloys are covered in the literature listed on pages 348 to 350.

WROUGHT PRODUCTS

Nomenclature and Products

Wrought products in various aluminum alloys are fabricated by such operations as rolling, extruding, drawing and forging. The wrought alloys are designated by a combination of numbers and letters which indicate the alloy, class of material and temper. The examples given in the following paragraphs indicate the general significance of the terms in alloy designations.

A widely used heat-treated wrought aluminum alloy is 6061-T6. The number, "6061," identifies the alloy composition; the use of four digits in this number distinguishes it as a wrought, rather

than a cast alloy; the letter "-T" shows that the metal has been heat treated; and the final "6" indicates the type of heat treatment.

An example of nonheat-treatable alloy is 3004-H32. The designation "3004" identifies alloy and wrought condition as in the heat-treated alloys; the letter "-H" signifies that temper is produced by cold-working, rather than heat treatment; the final number "32" indicates the specific temper which in turn relates to a definite set of mechanical properties for the alloy in question.

The "-F" (as fabricated) temper is of interest in some applications, as it is usually the lowest priced for any given alloy and product. It is not listed in some of the mechanical property tables because the properties are not guaranteed and may vary over a considerable range. Material so designated is fabricated by bringing it to the required dimensions and stopping there without any attempt to control the mechanical properties. The temper is a useful one for nonheat-treatable plate that is to be welded (and thus locally softened), for heat-treatable material which is to be heat treated by the user or for applications where neither maximum mechanical strength nor maximum workability is required.

Certain sheets, plates and tubes are produced with surface coatings called alclad coatings, which are metallurgically bonded to the core during hot-working. These alclad coatings are of an aluminum alloy of high resistance to corrosion which offers electrolytic protection to the core. The coatings protect not only the surfaces which they cover but also the cut edges and spots where the coating may be locally cut, scratched or abraded. The coatings are especially effective in preventing penetration into the core by corrosion attack and hence are widely used where local perforations would cause leakage as in a pressure vessel or pipe. Data on alclad products are given in Table 13, page 90.

Wrought aluminum alloy products are available in the form of shapes, plate, sheet, bar, tubes, pipe, rod, wire, forgings, rivets, bolts, nails and all other forms required for structural assemblies.

Nominal Compositions

The nominal compositions of wrought Alcoa aluminum alloys are given in Table 2a, page 33. Technical society specifications covering these alloys are indexed in Table 6a on page 71.

Physical Properties

Various physical properties of wrought alloys are given in Table 3a, pages 35 and 36. These include weight, coefficient of thermal ex-

pansion, modulus of elasticity, electrical conductivity and thermal conductivity. Modulus of elasticity is important in studies of structural stability as well as in the calculation of deformations and deflections caused by stress. Deflection, however, is dependent on dimensions and arrangement of parts as well as on the modulus of elasticity of the material. Desired stiffness can be provided by choosing suitable forms and sizes of members and by suitable distribution of metal. Thus the flexural stiffness of a flat sheet can be tripled simply by increasing its thickness 44 per cent. Modulus of elasticity is affected by temperature as indicated below.

Effect of Temperature on Modulus of Elasticity

Temperature, °F	Modulus of Elasticity in Per Cent of Room Temperature Value
−320	112
−110	105
− 20	102
+ 75	100
+212	98
+300	95
+400	90
+500	80

Mechanical Properties

Commercially pure aluminum has a typical yield strength of about 5 kips per sq in. in the fully annealed condition. By means of alloying and heat treatment, the typical yield strength can be increased to 80 kips per sq in. or more. The strongest commercial alloy, while only 3 per cent heavier than annealed commercially pure aluminum, has a yield strength 16 times as great.

The minimum mechanical properties of the various wrought aluminum alloy products at room temperature are given in Tables 4a to 4h inclusive. The principal mechanical property tables are based on *minimum* rather than typical values in recognition of the fact that engineers are insisting more and more that strength members be designed on the basis of minimum typical properties. A smaller and more realistic factor of safety can be used when design values are based on minimum rather than typical properties.

Most of the tensile properties listed in Table 4 are guaranteed minimum values. The rest of the tensile properties, and also the other quantities in the table, are corresponding minimum expected values that are not guaranteed. The minimum properties are the lowest values that would be expected for coupons selected in accordance with government and technical societies specifications. In at least 99 per cent of a product, the properties are expected to exceed the minimum values. Typical properties average about 15 per cent higher than the minimum. Tables of minimum mechanical properties guaranteed by Alcoa and tables of typical mechanical properties are available in another publication, the *Alcoa Aluminum Handbook*.

An unusual situation exists in the case of annealed tempers (designated by the letter "-O," as in 6061-O). In order to assure maximum workability, the specifications usually limit the maximum rather than the minimum strength of annealed products. The values shown in Tables 4a–4h, however, are the minimum expected strengths to be used for conservative design purposes.

The properties in Tables 4a–4h are for metal at room temperature (about 75°F) but are considered applicable to the range of ordinary temperatures, say from about 0° to 150°F. Tensile strength and yield strengths of wrought Alcoa aluminum alloys for other temperature conditions are given in Tables 8a and 8c, pages 76 to 79 and page 82. These data, presented in per cent of room temperature properties, provide some measure of the ability of the various alloys to withstand prolonged exposure at various temperatures. All the aluminum alloys become stronger and tougher at subnormal temperatures. Not all are well suited to elevated temperature applications, however, and some are not recommended for such use. For specific information concerning the suitability of the various alloys for use at elevated temperatures, the nearest sales office of Aluminum Company of America should be consulted. The information in Tables 8a and 8c can be used to approximate temperature effects on other properties by the rule that shear and bearing ultimate strengths are governed by the same percentages as ultimate tensile strength, whereas compressive, shear and bearing yield strengths are governed by the same percentages as tensile yield strength.

Stress-Strain Curve

A typical tensile stress-strain curve for aluminum alloys is shown in Fig. 1. It will be noted that this curve is a continuously rising curve and does not exhibit a flat spot or sharp break at the yield

strength. As is the case with other materials that yield gradually rather than abruptly, it has been necessary to adopt an arbitrary criterion of yield strength. The criterion used is that established by the American Society for Testing Materials in its *Standard Defini-*

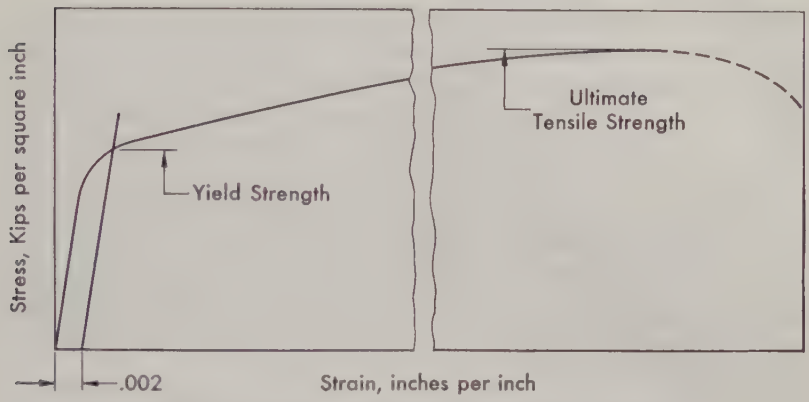

Fig. 1. Typical stress-strain curve for aluminum alloys.

tions of Terms Relating to Methods of Testing (*E6*) and is the stress at which the material exhibits a permanent set of 0.2 per cent (equivalent to 0.002 in. per inch of gage length).

Fatigue Properties

Tables 9 and 10, pages 83 to 85 present the approximate average fatigue strengths of aluminum alloys. It is not practicable, at present, to give minimum fatigue strengths. All fatigue specimens used to obtain the wrought-alloy data in these tables had smooth machined surfaces.

The fatigue strengths in Tables 9 and 10 should not be applied directly in design without suitable allowance for stress raisers such as holes, welds and re-entrant corners. A further discussion of designing to resist fatigue will be found in the design section of this handbook, page 107.

Resistance to Corrosion

The resistance to corrosion of a metal is a relative matter and depends on a comparison with other metals or with other alloys of the same metal. The corrosive environments and dissimilar components of construction encountered in service are so varied that it is impossible to indicate the performance expected from different alloys.

Approximate relative ratings for the resistance to corrosion of various alloys are given in Table 1a, page 26. These ratings are based on the relative average performance of the alloys when exposed without protection to natural corrosive environments, including sea water, industrial atmospheres and seacoast atmospheres.

The alloys rated A in Table 1a have high inherent resistance to corrosion. The alclad products should be given preference where maximum resistance to perforation by corrosion is required. Alclad 3003 for tube or pipe carrying corrosive waters, and Alclad 3004 for Alcoa industrial roofing sheet are two examples. The alclad high strength alloys have excellent resistance to corrosion, and when practicable the clad product should be used in those applications where damaging corrosion might otherwise occur.

The alloys with a B rating have a good over-all resistance to corrosion. The superiority of the alloys in class A to those in class B may only be realized under relatively severe conditions of exposure or in specific environments.

The alloys rated C and D are alloys of the aluminum-copper, aluminum-zinc-magnesium-copper or aluminum-copper-silicon types. The presence of relatively large amounts of copper or zinc reduces the over-all resistance to surface attack. Unlike the alloys with A and B ratings, these alloys may vary in performance depending upon the type of product, thickness of material and temper. The magnitude of the differences, even for the same alloy, may be appreciable.

Maximum resistance to corrosion of the naturally aged tempers (-T3, -T4, -T36) of alloys 2011, 2014, 2017 and 2024 is dependent on a rapid quench. Sections thicker than $\frac{1}{8}$ in. to $\frac{1}{4}$ in., because of their slower rate of quench, are not as resistant to corrosion as the thinner sections and are given a D rating in Table 1a. Artificial aging of the thicker sections to the -T6 or -T8 tempers usually effects a marked improvement in resistance to corrosion.

The need for protective coatings will depend on the alloy, the dissimilar metals involved and the nature of the environment. In most cases the alloys rated A and B will perform satisfactorily without paint protection. Alloys rated C and especially those rated D should, as a general rule, be protected by paint or other suitable coatings, if exposed to corrosive environments. Corrosion is more apt to occur in joints, crevices, or where the metal is held in contact with water absorptive materials. Protection of these surfaces with paint or seam compounds is advisable and is always recommended for alloys with ratings of C and D.

For additional details on resistance to corrosion, the booklet *Alcoa Aluminum Handbook* should be consulted.

MANUFACTURE OF WROUGHT PRODUCTS

The various Alcoa products considered in this handbook are listed in Table 1a, page 26. Maximum commercial sizes for the various products are given on pages 298 to 319, and commercial tolerances are shown on pages 277 to 297. Items somewhat beyond these limits may be made the subject of special inquiry.

Rolled Products

Sheet, plate, shapes, rod and bar are produced by rolling. In addition to structural shapes, such as angles and channels, Aluminum Company of America has the facilities to supply special rolled sections. These should be made the subject of special inquiry.

Extruded Products

Extruded products are produced by forcing metal (hot, but not molten) through an orifice having the shape of the desired cross section. Size limitations of extruded shapes were very greatly expanded in 1954 when a new 14,000-ton extrusion press started production. Nominal limitations are maximum cross-sectional area, 60 sq in.; maximum diameter of circumscribing circle, 23 in.; maximum length, 90 ft; maximum weight per piece, 2,300 lb. Information on specific proposals may be obtained from the nearest sales office of Aluminum Company of America.

Many of the extruded shapes now available without die charge are useful in supplementing standard structural shapes. Maximum economy of metal and fabricating cost can often be effected by designing members especially adapted to a given purpose, and the resulting saving in metal alone frequently pays for the new die promptly.

Seamless tubes are produced in a variety of alloys and sizes. The commercial range of diameters and wall thicknesses of round tubes is given in Table 122, page 313. Oval, square, rectangular, streamline and special-shape tubes are also available.

Forged Products

Die forgings are produced in a number of strong aluminum alloys as indicated in Table 4h, page 60. Some of these, such as 7075 and 6061, are regular Alcoa alloys, available as sheet, extruded shapes,

rod, bar, etc. Other special compositions, such as 4032 and 2218, are available as forgings only and are for the most part used in high temperature aircraft power plant applications.

Rough "hand-forged" shapes are available in most of the forging alloys. These are produced by forging between flat dies. Very large pieces weighing up to two tons or more can be produced by this method from which finished parts can be machined. Hand forgings are usually specified when only a few pieces are required which do not justify the cost of constructing full closed-die equipment and when the details of design may still be undetermined.

Other Products

The wrought products mentioned in the preceding paragraphs are the ones of principal interest for strength members. Also important, however, are rivets, bolts, nuts, washers and screws which will be discussed more fully in the design section of this handbook. In addition, Alcoa produces such wrought products as foil, wire, drawn tube and impact extrusions.

Straightening and Flattening

Many of the various wrought products require straightening or flattening before they are ready for shipment. Rolling and stretching are the principal methods of straightening or flattening. Heat-treated products are straightened or flattened after the solution heat treatment. Any artificial aging is done after straightening or flattening.

Heat Treatment

The solution heat treatment of wrought alloys consists of heating at carefully controlled temperatures, varying from 860° to 980°F for different alloys and quenching in water. The time of soaking, after the metal is up to temperature, depends mainly on the thickness of the material. The sudden change in temperature, caused by the quench, may result in some distortion of the piece. This distortion is removed by subsequent rolling or stretching operations, but it must be given careful consideration where solution heat treatment is contemplated on a preformed member.

Some products are given a precipitation heat treatment or artificial aging in addition to the solution heat treatment. This artificial aging, at temperatures varying from 245° to 465°F does not produce perceptible distortion of the material. The details of time and temperature for various heat treatments are given in Table 7a, page 73.

The alloy designation system for Alcoa aluminum castings is similar to that for wrought products as given on page 9, except that the alloy number contains only two or three digits instead of four. The letter "-F" is used to designate the as-cast condition. The nominal compositions of casting alloys are given in Table 2b, page 34. Technical society specifications covering these alloys are indexed in Table 6b, page 72. Data on weight, modulus of elasticity, thermal expansion, electrical conductivity, thermal conductivity and heat treatment are presented in Tables 3b, pages 37 and 38, and 7b, page 75.

Casting Processes

In producing aluminum alloy castings, several different processes are used. The molten alloy may be poured into sand molds or into metal molds. In the latter method, the cores may be metal or they may be dry sand, the same as those used in the sand-casting process. When dry sand cores are used in a metal mold, the castings are designated "semipermanent-mold castings." Aluminum alloys are also poured in plaster molds to produce plaster process and investment castings. In the die-casting process, the molten alloy is forced into alloy steel molds under pressure. Single sand castings weighing up to 7,000 lb, semipermanent-mold castings up to 500 lb, permanent-mold castings up to 400 lb and die castings of about 20 lb have been produced in aluminum alloys.

Mechanical Properties

Minimum mechanical properties of Alcoa aluminum sand, permanent-mold and die-casting alloys are shown in Tables 4j, 4k and 4m, pages 61 to 66. These values are based on tests of standard specimens individually cast and tested without machining the surface. As is the case with the other cast metals, the properties so determined are not necessarily the same as those of test bars cut from commercial castings, but may be higher or lower. In the design of castings, the services of the engineering and technical staff of Aluminum Company of America are available on request.

The remarks concerning the stress-strain curve and effects of temperature on properties of wrought alloys in preceding pages are equally applicable to the casting alloys. Data showing the effects of temperature on mechanical properties are given in Table 8b, pages 80 and 81.

Fatigue Properties

Included in Tables 9 and 10, pages 83 to 85, are some approximate average fatigue properties for cast alloys. The fatigue specimens used had smooth machined surfaces except those for die castings which had the original cast surface with only the flash removed. The specimens were separately cast bars prepared in green-sand molds for sand-cast alloys and in metal molds for the others.

No attempt has been made to give individual fatigue strength values for the various casting alloys, but instead they have been grouped because fatigue strength is more influenced by quality and soundness of the castings than by differences in alloy and temper. Permanent-mold alloys in general show at least as high fatigue strengths as sand castings, with maximum values as much as 10 kips per sq in. higher at 100,000 cycles and 4 kips per sq in. higher at 500 million cycles. The excellent fatigue strength of die-casting alloys is evident in Table 9.

The fatigue strengths in Tables 9 and 10 should not be applied directly in design without suitable allowance for stress raisers such as holes, and re-entrant corners, even though tests show that such stress raisers are less severe in their effect on castings than in their effect on wrought products.

FABRICATION OF ALUMINUM ALLOY STRUCTURES

Forming

Through proper choice of alloy, temper, forming methods and tools, a great variety of forming operations can be performed on aluminum alloys. Ordinary types of presses, brakes and rolls are suitable for this work, but it is highly desirable that the surfaces of the tools which come in contact with the aluminum alloys be smooth and free from tool marks, dents or rough edges which would tend to tear or score the metal. For difficult operations, lubricants, such as heavy oils or tallow mixed with a small amount of mineral oil, can be used to advantage.

In making bends that approach the minimum radius, the surfaces and edges of the metal should be smooth. Scratches, nicks and sharp corners should be removed. A pencil or crayon, rather than a punch or scriber, should be used for marking bend lines.

Shape of section and thickness of metal determine the severity of forming that can be accomplished successfully for a given alloy and temper. Table 11, pages 86 to 88, indicates the cold bend radii that are commonly used for various Alcoa alloys and thicknesses of sheet

or plate. These values have been established by tests and practical experience, but it is advisable to try out the operation with available tools on sample pieces where a minimum bend radius is necessary.

If a given forming operation is too severe for the final temper of a heat-treated alloy, forming can be done either hot or cold on annealed material and strength developed by subsequent heat treatment. Heat-treated alloys can also be formed at room temperature in the "freshly quenched" or "-W" temper, which is much more formable than the fully heat-treated temper. After the forming is completed, the part is aged to develop full strength. Since alloys in the "freshly quenched" temper age-harden naturally at room temperature, maximum formability is available immediately after quenching. More detailed information on this and related subjects is given in the booklet entitled *Forming Alcoa Aluminum.*

If it is not convenient or possible to form an article from a heat-treated material in the manner outlined above, hot-forming is sometimes used. Generally, the higher the temperature, the greater the formability will be. Too high temperatures must not be used, however, as considerable loss in strength may occur. The times and temperatures recorded in the accompanying table may be used as a guide during reheating for hot-forming. Under these conditions of time and temperature, the losses in strength as a result of reheating generally will not exceed about 5 per cent. It is to be understood that these are maximum accumulated times of reheating and that, in most cases, equal formability will be obtained with shorter periods of heating.

Maximum Reheating Times for the Forming of Heat-treatable Alloys at Various Temperatures

Temperature	2014–T6	2024–T81	2024–T86	6061–T6	7075–T6
500°F	No	No	No	No	No
450°F	To temp.	5 min	5 min	5 min	No
425°F	To temp.	15 min	15 min	15 min	To temp.
400°F	5–15 min	30 min	30 min	30 min	5–10 min
375°F	30–60 min	1 hr	1 hr	1–2 hr	30–60 min
350°F	2–4 hr	2–4 hr	2–4 hr	8–10 hr	1–2 hr
325°F	8–10 hr	.....	.....	50–100 hr	2–4 hr
300°F	20–50 hr	20–40 hr	10–20 hr	100–200 hr	10–12 hr

Reheating of 2014-T3, 2014-T4, 2024-T3 or 2024-T4 products is not recommended unless it is definitely known that the part will later be artificially aged to 2014-T6, 2024-T81 or 2024-T86. Generally, any reheating of sufficient value to improve materially the form-

ability will lower the resistance to corrosion of room-temperature aged products of 2014 and 2024 to an undesirable degree. An exception to this statement may be made for alclad sheet.

Machining

Machining operations can be readily performed using the same methods and equipment as with other metals, but for best results cutting tools must be specially ground. Tools should have keen cutting edges with more side and top rake than is usual for steel. In all machining operations, a liberal use of a cutting compound is desirable. For detailed discussion, the booklet *Machining Alcoa Aluminum* should be consulted.

Shearing

Sheet, plate and shapes of alloys other than 7075-T6, in thicknesses of ½ in. or less, can be sheared on any of the types of equipment used for other metals. Blades should be sharp and clearances adjusted to give smooth cuts. Material thicker than ½ in. should be sawed or routed. In the case of 7075-T6, the limiting thickness is about 0.1 in. rather than ½ in.

Sawing and Routing

Straight, curved and coping cuts can be made by saws. Lubricants of the soluble oil type are recommended. For straight cuts, stationary or portable circular saws are used, while band saws are used for curved or coping cuts. In any type of work, high blade speeds are desirable. A speed of 5,000 fpm is recommended for band saws, while a peripheral speed of 10,000 fpm gives good results with circular saws. The saw teeth should be fairly coarse with a slight set and a slight amount of front rake. Special routing machines are available which cut varied profiles from aluminum sheet or plate rapidly and efficiently.

Punching, Reaming, Drilling

Rivet or bolt holes in primary-load-carrying members should be drilled, or subpunched and reamed. The amount by which the diameter of a subpunched hole is smaller than that of the finished hole should be at least one-quarter of the thickness of the piece and in no case less than 1/32 in. Both single- and multiple-type punches such as used on structural steel are suitable for aluminum alloys. The punch should be accurately centered in the die and a suitable radial clearance should be provided. Cutting edges of both punches

and dies should be sharp. In punching patterned tread plate, the punch should enter from the pattern surface of the plate.

Reamers should be of the high-speed, spiral-fluted type. Reaming operations on aluminum alloys are about twice as fast as the same work in steel.

Twist drills used on aluminum alloys should be kept sharp and constantly lubricated with a soluble oil. Drill speeds can be increased about 50 per cent above those used for steel. Special drills with more than the normal number of twists per inch can be used to advantage where a large amount of work is to be done. A double-fluted twist drill with a spiral angle of 47° gives good results on aluminum alloys.

Riveting

Aluminum alloy rivets are preferred for the fabrication of aluminum alloy structures, although cold-driven annealed steel rivets have been used successfully for some applications. Strengths and dimensions of aluminum alloy rivets are given on page 168 and pages 170 and 171, respectively. In any riveting operation, it is desirable that the clearance of the rivet in the hole be held to a minimum.

Squeeze-type riveters should be used on aluminum rivets where possible. Pneumatic hammers and back-up tools should be heavier than those used for hot steel rivets of the same size. The conepoint type of driven head minimizes driving pressure and has a good appearance.

Cold-driving is used for 6053-T61, 6061-T6 and 2117-T4 alloy rivets as received from the manufacturer. Rivets with conepoint heads in sizes up to $\frac{5}{8}$-in. diameter can be driven with a pneumatic hammer. Large rivets should be squeeze driven.

Cold-driving in the as-quenched temper is used for 2017, 2024 and 6061 alloy rivets where proper heat-treating equipment is available. Such rivets are heat treated, quenched and driven immediately to take advantage of the workability of the metal before age hardening occurs at room temperature. This "as-quenched" workability can be retained for 8 to 10 hours by refrigerating the rivets to 32°F or less and storing at this temperature until used. The use of as-quenched rivets is normally restricted to rivets smaller than about $\frac{3}{8}$ in. for 2017 and 2024 and smaller than $\frac{5}{8}$ in. for 6061 alloy.

Hot-driving is often desirable for rivets over $\frac{1}{2}$-in. diameter, since driving pressures are only one-fifth to one-third as great as for corresponding cold rivets. For hot-driving, 6061 rivets should be brought to a temperature of 990° to 1050°F in a furnace having

accurate temperature control. Rivets must be transferred from the furnace to the work and driven in the least possible time, as quenching is obtained by contact with cold metal and tools. Rivets of 7277 alloy can be hot-driven using a similar procedure except that the heating range is 850° to 975°F.

Experience with many riveting operations, on all types of structures of heat-treated aluminum alloys, has proved that distortion is no greater than in steel structures. When riveting softer grades of aluminum, special care must be exercised to avoid overdriving. The driven head should, where possible, be formed on the side of the work having the greater thickness or hardness of metal. Details of riveting operations on aluminum alloys are given in the booklet *Riveting Alcoa Aluminum.*

Welding

Certain alloys of aluminum may be welded by torch, electric arc and resistance welding methods. Welding decreases the strength of tempered material because of the softening effect of the heat. In some cases, parts are heat treated after welding to restore strength. Welding processes for aluminum alloys are being developed rapidly. The booklet *Welding Alcoa Aluminum* gives much valuable information on this subject.

Arc-cutting and Flame-cutting

Aluminum alloys can be cut with a tungsten arc in an inert gas-hydrogen atmosphere or with an inert gas consumable electrode process using a steel electrode. Both heat-treatable and nonheat-treatable alloys can be shaped by arc-cutting. In heat-treatable materials, arc-cutting sometimes causes small edge cracks, which may have to be removed by trimming the edges after cutting. The cutting methods for ferrous materials that use oxygen for cutting are not suitable for use on the aluminum alloys.

Painting

Although aluminum and its alloys are highly resistant to corrosion, it is frequently desirable, when severe conditions of exposure are to be encountered, to protect with paint as in the case of other metals. If painting is to be used, it is important that the surfaces be properly prepared immediately before priming. Dirt accumulations may be removed with brushes. If there is an excessive amount of oil or grease present, this must first be removed by means of solvent. The surface should then be chemically treated in the following manner:

Parts should be immersed in or swabbed with a solution of phosphoric acid and organic grease solvents diluted with water. There are a number of proprietary solutions of this type available and they are usually diluted with water in the ratio of 1:3. The solution temperature should be between 50° and 90°F. The solution should remain in contact with the metal for not less than 5 minutes. Residual solution must then be thoroughly removed with clean water and the surface dried. This treatment not only cleans the metal but also forms a thin film of aluminum phosphate on the surface which helps protect the aluminum and promote paint adhesion.

Where chemical cleaning is impracticable, mild sandblasting methods may be used on sections more than $\frac{1}{8}$ in. thick.

For best results, it is important that all contacting aluminum alloy surfaces be protected. A zinc chromate primer, Army-Navy Specification JAN-P-735 or equivalent, applied to both surfaces and allowed to dry before assembly, is recommended. A suitable nonhardening calking compound is also effective, if applied so as to exclude all moisture from the finished joint. Surfaces to be coated in this latter manner may be treated as previously described or merely cleaned with a solvent such as mineral spirits or benzine. For severe conditions of exposure, both priming paint and joint compound should be used.

In all cases where aluminum members are to be fastened to steel members or other dissimilar metal parts, the aluminum should be kept from direct contact with such parts by painting the aluminum surfaces as described above and by painting the dissimilar metal with a suitable metal priming paint followed by a coat of aluminum paint. In addition, a suitable nonhardening calking compound may be employed.

Aluminum surfaces to be placed in contact with concrete or masonry construction should, before installation, be given a heavy coat of an alkali-resistant bituminous paint. The quality of the bituminous paint used should be equal to that called for in Military Specification MIL-P-6883. The paint should be applied as it is received from the manufacturer without the addition of any thinner. This treatment is not required in locations where the contacting surfaces remain substantially dry.

Noncontacting aluminum alloy surfaces are primed with zinc chromate primer in accordance with Army-Navy Specification JAN-P-735 or equivalent.

All surfaces except contacting surfaces should be given a second coat of paint consisting of two pounds of aluminum paste pigment

(ASTM Specification D962,* Type II, Class B) per gallon of varnish meeting Federal Specification TT-V-81b, Type II or equivalent. Sufficient Prussian blue may be added to permit detection of an incomplete application of a subsequent coat of aluminum paint.

The final assembled aluminum structure may be finished with one coat of aluminum paint of the same type described in the previous paragraph, except that the Prussian blue is omitted. One or more coats of alkyd base enamel pigmented to meet any desired color scheme may be substituted for aluminum paint.

SELECTION OF ALLOY

The selection of the proper alloy for a specific application depends on the requirements of strength, durability and economy and is limited by proposed fabricating methods and by availability of the products required. Tables 1a and 1b, pages 26 to 32, will assist the engineer in making a preliminary selection. All the alloys, tempers and products covered in this book are commercially produced by Alcoa. Many items are carried in various independent warehouses in larger cities throughout the country. For small projects, and tryouts for big ones, it is always worth while to consult these warehouses. If the metal is available from them, delivery is more prompt than mill shipment, and on small lots their prices are lower. Alcoa endeavors to maintain a stock of the most frequently used rolled structural shapes at Massena, New York. Other material within the commercial limitations listed in Tables 104 to 128, pages 298 to 319, can be ordered from the mill in required quantities. In some cases these limitations can be exceeded, and when this would be advantageous to the user special inquiry should be made. The nearest sales office of Aluminum Company of America will assist in the selection of alloys and products that are suitable and also most readily available.

*Only the basic number is shown since Alcoa products are manufactured to the latest issue of the specification. The complete number would indicate the year of issue.

Tables of Properties

TABLE 1a

Characteristics—WROUGHT ALLOYS

Alloy	Usual Commercial Tempers	Products①									Approximate Relative Ratings Based on Various Characteristics②								Typical Uses
		Sheet and Plate	Rod	Bar	Std. Str. Shapes	Extruded Shapes	Extruded Tube	Drawn Tube	Pipe	Forgings	Strength③	Workability (Cold)	Resistance to Corrosion	Weldability (Arc)	Machinability	Electrical Conductivity	Forgeability	Hardness	
EC	O, H12, H14, H16, H18, H19	..	√	√	..	..	..	..	..	..	D,C	A,C	A	A	D,C	A	....	D	Electrical conductors.
1060	O, F, H112, H12, H14	⑤	..	..	..	⑤	⑤	⑤	⑤	..	D,C	A,C	A	A	D,C	A	....	D	Chemical equipment and railroad tank cars, for liquids such as hydrogen peroxide.
1100	O, F, H112, H12, H14, H16, H18	√	√	√	..	..	..	..	..	√	D,C	A,C	A	A	D,C	B	A	D,C	Sheet metal work, spun hollow ware and decorative parts.
2011	T3, T8	..	√	√	..	..	..	..	..	..	B	C,D	C⑥	D	A	C	....	B	Screw machine products.
2014	T4, T6	..	√	√	√	√	√	....	....	√	A	C,D	C⑥	B	B	C	C	B,A	Heavy-duty structures, aircraft structures and truck frames.
Alclad 2014	T3, T4, T6	√	..	..	..	..	..	..	..	..	A	C,D	A	B	B	C	....	....	Heavy-duty structures and aircraft structures.
2017	T4	..	√	√	..	..	..	..	..	..	A	C	C⑥	B	B	D	....	B	Screw machine products.
2018	T61	..	..	..	..	..	..	..	..	√	A	....	C	B	B	C	C	B	Aircraft engine cylinder heads and pistons.
2024	T3, T36, T4	√	√	√	..	√	√	√	....	....	A	C,D	C⑥	B	B	D	....	A	Aircraft structures, truck wheels and screw machine products.
Alclad 2024	T3, T36, T4, T81, T86	√	..	..	..	..	..	..	..	..	A	D	A	B	B	D	....	....	Aircraft structures and truck bodies.
2218	T72	..	..	..	..	..	..	..	..	√	B	....	C	B	B	C	D	B	Aircraft engine cylinder heads and pistons, jet engine impellers and compressor rings.

See page 29 for footnotes.

Alloy	Usual Commercial Tempers	Products①									Approximate Relative Ratings Based on Various Characteristics②								Typical Uses
		Sheet and Plate	Rod	Bar	Std. Str. Shapes	Extruded Shapes	Extruded Tube	Drawn Tube	Pipe	Forgings	Strength③	Workability (Cold)	Resistance to Corrosion	Weldability (Arc)	Machinability	Electrical Conductivity	Forgeability	Hardness	
3003	O, F, H112, H12, H14, H16, H18	√	√	√	. .	√	√	√	√	√	D,C	A,C	A	A	D,C	C	A	D,C	Cooking utensils, chemical equipment, pressure vessels, storage tanks, piping, architectural applications and builders' hardware.
Alclad 3003	O, F, H112, H12, H14, H16, H18	√	. .	. .	. .	. .	. .	④	④	. .	D,C	A,C	A	A	D,C	C	. . . .	. . . .	Teakettles, chemical equipment, heat exchanger tubes, pressure vessels, storage tanks and flashing.
3004	O, F, H112, H32, H34, H36, H38	√	. .	. .	. .	. .	. .	. .	. .	. .	C	A,C	A	A	D,C	C	. . . .	C	Special sheet metal work, shoe eyelets, screw shells, pressure vessels and storage tanks.
Alclad 3004	O, F, H112, H32, H34, H36, H38	√	. .	. .	. .	. .	. .	. .	. .	. .	C	A,C	A	A	D,C	C	. . . .	. . . .	Industrial building sheet and flashing.
4032	T6	. .	. .	. .	. .	. .	. .	. .	. .	√	B	. . . .	C	B	C	D	C	B	Pistons.
5005	O, H12, H14, H16, H18, H32, H34, H36, H38	√	. .	. .	. .	. .	. .	. .	. .	. .	D,C	A,C	A	A	D,C	C	A	D,C	Mobile home siding.
5050	O, F, H112, H32, H34, H36, H38	√	. .	. .	. .	. .	. .	√	. .	. .	C	A,C	A	A	D,C	B	. . . .	D,C	Decorative refrigerator parts, builders' hardware and coiled tubes.
5052	O, F, H112, H32, H34, H36, H38	√	√	√	. .	. .	. .	√	. .	. .	C	A,C	A	A	D,C	D	. . . .	C,B	Sheet metal work, home appliances, bus, truck and marine applications, hydraulic tubes, street light standards, clock plates and parts.

See page 29 for footnotes.

Continued on next page

TABLE 1a

Characteristics—WROUGHT ALLOYS—*Concluded*

Alloy	Usual Commercial Tempers	Products①									Approximate Relative Ratings Based on Various Characteristics②								Typical Uses
		Sheet and Plate	Rod	Bar	Std. Str. Shapes	Extruded Shapes	Extruded Tube	Drawn Tube	Pipe	Forgings	Strength③	Workability (Cold)	Resistance to Corrosion	Weldability (Arc)	Machinability	Electrical Conductivity	Forgeability	Hardness	
5083	O, H112, H113	√	. .	. .	. .	√	. .	. .	. .	. .	B	C	A⑤⑦	B	D,C	D	....	B	Welded structures (high strength).
5086	O, H112, H32, H34, H36	√	. .	. .	. .	√	. .	. .	. .	. .	C, B	A, C	A⑥ B	A	D,C	D	....	C, B	Welded structures (medium strength).
5154	O, H112, H32, H34, H36, H38	√	. .	. .	. .	√	√	. .	. .	. .	C, B	A, C	A⑥	A	D,C	D	....	C, B	Welded structures (medium strength), pressure vessels, storage tanks, truck and marine applications.
5454	O, H112, H311, H32, H34	√	. .	. .	. .	√	. .	. .	. .	. .	C, B	A, C	A	A	D,C	D	....	C, B	Welded structures (elevated temperatures).
5456	O, H112, H311, H321	√	. .	. .	√	√	. .	. .	. .	. .	B	C	A⑥⑦	B	D,C	D	....	B	Welded structures (high strength), pressure vessels, storage tanks, truck and marine applications.
6061	T4, T6, T62, T81, T91, T913	√	√	√	√	√	√	√	√	√	C, B	C, D	A	A	C	C	....	C, B	Heavy-duty structures where resistance to corrosion is necessary, bridge railings, marine applications, furniture, truck bodies, truck frames, trailers, railroad cars, tread plate, pipe and pipe flanges.

Alloy	Usual Commercial Tempers	Products①									Approximate Relative Ratings Based on Various Characteristics②								Typical Uses
		Sheet and Plate	Rod	Bar	Std. Str. Shapes	Extruded Shapes	Extruded Tube	Drawn Tube	Pipe	Forgings	Strength⑧	Workability (Cold)	Resistance to Corrosion	Weldability (Arc)	Machinability	Electrical Conductivity	Forgeability	Hardness	
Alclad 6061	T4, T6	√	.	.	.	.	.	.	.	.	C, B	C	A	A	C	C	.	.	Truck body siding, corrosive exposure.
6062	T4, T6, T62	.	.	.	√	√	√	√	.	.	C, B	C	A	A	C	C	.	C, B	Alternate for 6061 alloy.
6063	T4, T42, T5, T6, T83, T831, T832	.	.	.	.	√	√	√	√	.	C, B	B, C	A	A	C	B	.	C, B	Pipe railings, builders' hardware, windows, store fronts and architectural applications.
6151	T6	.	.	.	.	.	.	.	.	√	B	.	B	A	C	C	A	B	Intricate forgings for machine and automotive parts.
7075	T6	√	√	√	.	√	√	.	.	√	A	D	C	D	B	D	D	A	Aircraft structures and keys.
Alclad 7075	T6	√	.	.	.	.	.	.	.	.	A	D	A	D	B	D	.	.	Aircraft structures.
7079	T6, T65	.	.	.	.	.	.	.	.	√	A	D	C	D	B	D	C	A	Aircraft structures.
7178	T6	√	.	.	.	√	√	.	.	.	A	D	C	D	B	D	.	A	Aircraft structures.
Alclad 7178	T6	√	.	.	.	.	.	.	.	.	A	D	A	D	B	D	.	.	Aircraft structures.

①Not all products are available in all tempers—see Table 4.

②A, B, C and D are arbitrary relative ratings in decreasing order of merit. Where two letters are shown, that on the left is for the softest temper listed and that on the right for the hardest temper listed.

③See Table 4 for minimum strength values.

④Drawn tubes and pipe available with alclad coating on the inside, the outside, or both sides.

⑤In thicknesses of about ½ in. and over, these alloys in the -T3, -T4 and -T36 tempers have a "D" rating.

⑥This rating may be changed for cold-worked material held at elevated temperatures for long periods. Further information can be obtained at the nearest Alcoa sales office.

⑦These alloys in the -H112 temper have a "B" rating.

⑧Available as special products, which are not in regular mill production but may be supplied in some cases. Further information can be obtained at the nearest Alcoa sales office.

TABLE 1b

Characteristics—CASTING ALLOYS

Alloy	Usual Commercial Tempers	Types of Castings			Approximate Relative Ratings Based on Various Characteristics①								Typical Uses
		Sand	Permanent Mold	Die	Strength②	Castability	Resistance to Corrosion	Weldability (Torch and Arc)	Machinability	Electrical Conductivity	Pressure Tightness	Hardness	
13	F	..	..	√	B	B	B	....	C	C	A	....	Typewriter frames, outboard motor pistons, dental equipment, instrument cases. A general-purpose alloy for large intricate parts with thin sections.
43	F	√	√	..	D	A	B	A	D	C	A	D	General-purpose casting alloy, cooking utensils, architectural and marine applications and pipe fittings.
C113	F	..	√	..	B	B	D	B	B	D	B	B	Washing machine agitators, automotive cylinder heads and timing gears.
122	T551, T61, T65	√	√	..	B,A	C	D	D	A	C	C	A	Bushings, bearing caps and meter parts.
F132	T5	..	√	..	B	B	C	C	C	D	B	B	Automotive and diesel engine pistons.
B138	F	..	√	..	B	C	D	C	B	D	C	B	Sole plates for electric hand irons.
142	T21, T571, T61, T77	√	√	..	C,A	C	C	D	B	B,C	C	C,B	Heavy-duty pistons and air-cooled cylinder heads.
195	T4, T6, T62	√	..	..	B	C	C	C	B	C	C	C,B	Machinery and aircraft structural members.
B195	T4, T6, T7	..	√	..	B	C	C	C	B	C	C	C,B	Aircraft fittings, gear housings and gun control parts.
214	F	√	..	..	C	C	A	B	A	C	D	C	Food handling and chemical equipment, marine hardware and architectural applications.

See page 32 for footnotes.

Alloy	Usual Commercial Tempers	Types of Castings			Approximate Relative Ratings Based on Various Characteristics①								Typical Uses
		Sand	Permanent Mold	Die	Strength②	Castability	Resistance to Corrosion	Weldability (Torch and Arc)	Machinability	Electrical Conductivity	Pressure Tightness	Hardness	
A214	F	..	✓	..	C	C	A	B	A	C	D	C	Cooking utensils.
B214	F	✓	..	..	C	C	A	B	B	C	C	C	Cooking utensils and pipe fittings.
F214	F	✓	..	..	C	C	A	B	A	C	D	C	Alumilite coated architectural parts and ornamental hardware.
218	F	..	..	✓	A	D	A	....	A	D	D	....	Die castings requiring high strength, ductility and resistance to corrosion, such as marine fittings and hardware.
220	T4	✓	..	..	A	D	A	D	A	D	D	C	Sand castings requiring strength and shock resistance, such as aircraft structural members.
319	F, T6	✓	..	..	C,B	B	C	B	B	D	B	C,B	General-purpose sand castings, engine parts, automotive cylinder heads and piano plates.
333	F, T5, T6, T7	..	✓	..	B,A	B	C	B	B	D,C	B	B	General-purpose permanent-mold castings, engine parts, gas meter housings and regulator parts.
355	T51, T6, T61, T62, T7, T71	✓	✓	..	C,B	A	B	B	B	C,B	A	C,B	Crankcases, accessory housings and aircraft fittings.
C355	T61, T62	..	✓	..	B,A	A	B	B	B	C	A	C,B	Castings requiring high strength such as missile and aircraft structural parts.
356	T51, T6, T7, T71	✓	✓	..	C,B	A	B	B	B	C,B	A	C,B	Transmission cases, truck-axle housings and wheels, cylinder blocks, railway tank car fittings, marine hardware, valve bodies and bridge railing parts.

See page 32 for footnotes.

Continued on next page

TABLE 1b

Characteristics—CASTING ALLOYS—*Concluded*

Alloy	Usual Commercial Tempers	Types of Castings			Approximate Relative Ratings Based on Various Characteristics①								Typical Uses
		Sand	Permanent Mold	Die	Strength②	Castability	Resistance to Corrosion	Weldability (Torch and Arc)	Machinability	Electrical Conductivity	Pressure Tightness	Hardness	
A356	T6, T61	..	√	..	C, B	A	B	B	B	C	A	C, B	Missile parts, aircraft structural members, highway posts and truck parts.
360	F	..	..	√	A	A	B	....	C	D	A	....	General-purpose die castings, cover plates and instrument cases.
380	F	..	..	√	A	B	C	....	C	D	B	....	General-purpose die castings.
384	F	..	..	√	A	A	C	....	B	D	B	....	A general-purpose alloy for large intricate parts with thin sections.
A612	F	√	..	..	B	C	B	C	A	C	D	C	General-purpose sand castings for brazing.
C612	F	..	√	..	B	D	B	C	A	B	D	C	Torque converter blades and brazed parts.
750	T5	..	√	..	D	D	C	D	A	B	D	D	Bearings, bushings, crosshead shoes and other castings requiring good bearing characteristics.
A750	T5	√	√	..	D	D	C	D	A	B	C	D	Bearings, bushings and other castings requiring good bearing characteristics such as pump housings and gear cases.
B750	T5	..	√	..	C	D	C	D	A	B	D	C	Castings requiring good bearing characteristics and higher strength than is provided by alloys 750 and A750.

①A, B, C and D are arbitrary relative ratings in decreasing order of merit. Where two letters are shown, that on the left is for the softest temper listed and that on the right for the hardest temper listed.

②Refer to Table 4 for strength values.

TABLE 2a

Nominal Composition

WROUGHT ALLOYS

Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
EC	99.45% minimum aluminum								
1060	99.6% minimum aluminum								
1100	99% minimum aluminum								
2011	5.5	...	...	...	...	...	...	0.5	0.5
2014	4.4	0.8	0.8	0.4	...	...	...	...	...
2017	4.0	...	0.5	0.5	...	...	...	...	...
2018	4.0	...	...	0.6	...	2.0	...	...	...
2024	4.5	...	0.6	1.5	...	...	...	...	...
2025	4.5	0.8	0.8	...	...	...	...	...	...
2117	2.5	...	...	0.3	...	...	...	...	...
2218	4.0	...	...	1.5	...	2.0	...	...	...
3003	...	...	1.2	...	...	...	...	...	...
3004	...	...	1.2	1.0	...	...	...	...	...
4032	0.9	12.2	...	1.1	...	0.9	...	...	...
4043	...	5.0	...	...	...	...	...	...	...
5005	...	...	...	0.8	...	...	...	...	...
5050	...	...	...	1.4	...	...	...	...	...
5052	...	...	...	2.5	...	...	0.25	...	...
5083	...	...	0.8	4.45	...	...	0.10	...	...
5086	...	...	0.45	4.0	...	...	0.10	...	...
5154	...	...	...	3.5	...	...	0.25	...	...
5454	...	...	0.8	2.75	...	...	0.10	...	...
5456	...	...	0.8	5.25	...	...	0.10	...	...
6053	...	0.7	...	1.3	...	...	0.25	...	...
6061	0.25	0.6	...	1.0	...	...	0.25	...	...
6062	0.25	0.6	...	1.0	...	...	...	...	...
6063	...	0.4	...	0.7	...	...	...	...	...
6151	...	1.0	...	0.6	...	...	0.25	...	...
7072	...	...	...	...	1.0	...	...	...	...
7075	1.6	...	...	2.5	5.6	...	0.3	...	...
7079	0.6	...	0.20	3.3	4.3	...	0.20	...	...
7178	2.0	...	...	2.7	6.8	...	0.30	...	...
7277	1.25	...	...	2.0	4.0	...	0.25	...	...

TABLE 2b

Nominal Composition

CASTING ALLOYS

Alloy	Types of Castings			Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder					
	Sand	Permanent Mold	Die	Copper	Silicon	Magnesium	Zinc	Nickel	Tin
13	..	..	✓	....	12.0	....	....	....	....
43	✓	✓	✓	....	5.0	....	....	....	....
85	..	..	✓	4.0	5.0	....	....	....	....
C113	..	✓	..	7.0	3.5	....	....	....	....
122	✓	✓	..	10.0	....	0.2	....	....	....
F132	..	✓	..	3.0	9.5	1.00	....	....	....
B138	..	✓	..	10.0	4.0	0.60	....	....	....
142	✓	✓	..	4.0	....	1.5	....	2.0	....
195	✓	..	..	4.5	0.8	....	....	....	....
B195	..	✓	..	4.5	2.5	....	....	....	....
212	✓	..	..	8.0	1.2	....	....	....	....
214	✓	..	..	....	....	3.8	....	....	....
A214	..	✓	..	....	....	3.8	1.8	....	....
B214	✓	..	..	....	1.8	3.8	....	....	....
F214	✓	..	..	....	0.5	3.8	....	....	....
218	..	..	✓	....	....	8.0	....	....	....
220	✓	..	..	....	....	10.0	....	....	....
319	✓	..	..	3.5	6.3	....	....	....	....
333	..	✓	..	3.8	9.0	....	....	....	....
355	✓	✓	..	1.3	5.0	0.5	....	....	....
C355	..	✓	..	1.3	5.0	0.50	....	....	....
356	✓	✓	..	....	7.0	0.3	....	....	....
A356	..	✓	..	....	7.0	0.30	....	....	....
360	..	..	✓	....	9.5	0.5	....	....	....
380	..	..	✓	3.5	9.0	....	....	....	....
384	..	..	✓	3.8	12.0	....	....	....	....
A612	✓	..	..	0.5	....	0.7	6.5	....	....
C612	..	✓	..	0.5	....	0.35	6.5	....	....
750	✓	✓	..	1.0	....	....	....	1.0	6.5
A750	✓	✓	..	1.0	2.5	....	....	0.5	6.5
B750	✓	✓	..	2.0	....	0.75	....	1.2	6.5

TABLE 3a

Typical Physical Properties

WROUGHT ALLOYS

Alloy	Weight, Lb per Cu In.	Modulus of Elasticity, Kips per Sq In.		Coefficient of Thermal Expansion per Degree F③, 68° to 212°F	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C, CGS Units
		Tension and Compression	Shear①			
EC-O	0 098	10,000	3,750	0.0000131	63	0.57
EC-H17	0 098	10,000	3,750	0.0000131	62.5	0.56
1060-O	0 098	10,000	3,750	0.0000131	62	0.56
1060-H14	0.098	10,000	3,750	0.0000131	62	0.56
1100-O	0.098	10,000	3,750	0.0000131	59	0.53
1100-H18	0 098	10,000	3,750	0 0000131	59	0.53
2011-T3	0 102	10,200	3,800	0.0000127	39	0.36
2011-T8	0.102	10,200	3,800	.....	45	0.41
2014-O	0 101	10,600	4,000	0.0000125	50	0.46
2014-T4	0 101	10,600	4,000	.....	34	0.32
2014-T6	0 101	10,600	4,000	0.0000128	40	0.37
2017-O	0 101	10,500	3,950	0 0000127	50	0.46
2017-T4	0.101	10,500	3,950	0.0000130	34	0.32
2018-O	0.102	10,600	4,000	0.0000124	50	0.46
2018-T61	0 102	10,600	4,000	0.0000126	40	0.37
2024-O	0 100	10,600	4,000	0.0000126	50	0.46
2024-T3	0.100	10,600	4,000	0 0000129	30	0.29
2024-T4	0 100	10,600	4,000	.....	30	0.29
2025-T6	0.101	10,400	3,900	0 0000129	40	0.37
2117-T4	0.099	10,300	3,850	0.0000131	40	0.37
2218-T72	0.101	10,600	4,000	0.0000124	40	0.37
3003-O	0.099	10,000	3,750	0.0000129	46	0.42
3003-H18	0.099	10,000	3,750	0.0000129	46	0.42
3004-O	0.098	10,000	3,750	0.0000129	42	0.39
3004-H38	0.098	10,000	3,750	0.0000129	42	0.39
4032-O	0.097	11,400	4,300	0.0000108	40	0.37
4032-T6	0.097	11,400	4,300	0.0000111	35	0.33
5005-O	0.098	10,000	3,750	0.0000132	52	0.48
5005-H38	0.098	10,000	3,750	0.0000132	52	0.48
5050-O	0.097	10,000	3,750	0.0000132	50	0.46
5050-H38	0.097	10,000	3,750	0.0000132	50	0.46

See page 36 for footnotes.

Continued on next page

TABLE 3a

Typical Physical Properties—*Concluded*

WROUGHT ALLOYS

Alloy	Weight, Lb per Cu In.	Modulus of Elasticity, Kips per Sq In.		Coefficient of Thermal Expansion per Degree F②, 68° to 212°F	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C, CGS Units
		Tension and Compression	Shear①			
5052-O	0.097	10,200	3,800	0.0000132	35	0.33
5052-H38	0.097	10,200	3,800	0.0000132	35	0.33
5083-O	0.096	10,000	3,750	.....	29	0.28
5083-H34	0.096	10,000	3,750	.....	29	0.28
5086-O	0.096	10,300	3,850	0.0000132	32	0.30
5086-H36	0.096	10,300	3,850	0.0000132	32	0.30
5154-O	0.096	10,200	3,800	0.0000133	32	0.30
5154-H38	0.096	10,200	3,800	0.0000133	32	0.30
5454-O	0.097	10,200	3,800	0.0000131	..	....
5454-H311	0.097	10,200	3,800	0.0000131	..	....
5456-O	0.096	10,300	3,850	0.0000133	29	0.28
5456-H321	0.096	10,300	3,850	0.0000133	29	0.28
6053-O & T5	0.097	10,000	3,750	0.0000128	45	0.41
6053-T4 & T6	0.097	10,000	3,750	0.0000131	40	0.37
6061-O	0.098	10,000	3,750	0.0000130	45	0.41
6061-T4	0.098	10,000	3,750	0.0000130	40	0.37
6061-T6	0.098	10,000	3,750	0.0000130	43	0.40
6062-O	0.098	10,000	3,750	0.0000130	..	....
6062-T4 & T6	0.098	10,000	3,750	0.0000130	45	0.41
6063-O	0.098	10,000	3,750	.....	58	0.52
6063-T42	0.098	10,000	3,750	0.0000130	50	0.46
6063-T5	0.098	10,000	3,750	0.0000130	55	0.50
6063-T6	0.098	10,000	3,750	0.0000130	53	0.48
6151-O	0.098	10,200	3,800	0.0000128	54	0.49
6151-T4	0.098	10,200	3,800	0.0000129	42	0.39
6151-T6	0.098	10,200	3,800	0.0000129	45	0.41
7075-O	0.101	10,400	3,900	0.0000129	..	....
7075-T6	0.101	10,400	3,900	0.0000131	33	0.31
7079-T6	0.099	10,400	3,900	0.0000131	32	0.30
7178-T6	0.101	10,400	3,900	0.0000130	31	0.29

①Poisson's ratio for aluminum alloys is one-third.

②Values of coefficient of thermal expansion for cold-worked tempers may vary slightly from lot to lot.

TABLE 3b

Typical Physical Properties

CASTING ALLOYS

Alloy	Weight, Lb per Cu In.	Modulus of Elasticity, Kips per Sq In.		Coefficient of Thermal Expansion per Degree F①, 68° to 212°F	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C, CGS Units
		Tension and Compression	Shear			
13–F	0.096	10,300	3,850	0.0000115	31	0.29
43 Annealed②	0.097	10,300	3,850	0.0000123	42	0.39
43–F	0.097	10,300	3,850	0.0000123	37	0.34
C113–F③	0.106	.....	.....	0.0000121	27	0.26
122–T2	0.107	10,700	4,000	0.0000124	41	0.38
122–T61	0.107	10,700	4,000	0.0000124	33	0.31
122–F③	0.107	10,700	4,000	0.0000124	34	0.32
F132–T5	0.100	11,200	4,200	0.0000115	26	0.25
B138–F	0.107	10,800	4,050	0.0000118	25	0.24
142–T21	0.102	10,300	3,850	0.0000126	44	0.40
142–T571④	0.102	10,300	3,850	0.0000126	34	0.32
142–T61③	0.102	10,300	3,850	0.0000126	33	0.31
142–T77	0.102	10,300	3,850	0.0000126	38	0.35
195–T4	0.102	10,000	3,750	0.0000127	35	0.33
195–T62	0.102	10,000	3,750	0.0000127	35	0.33
B195–T4③	0.101	10,100	3,800	0.0000124	33	0.31
B195–T6③	0.101	10,100	3,800	0.0000124	33	0.31
B195–T62	0.101	10,100	3,800	0.0000124	33	0.31
214 Annealed③	0.096	10,300	3,850	0.0000134	35	0.33
214–F	0.096	10,300	3,850	0.0000134	35	0.33
A214–F	0.097	.....	.....	0.0000134	34	0.32
B214–F	0.096	.....	.....	0.0000127	38	0.35
F214–F	0.096	.....	.....	0.0000131	36	0.34
218–F③	0.093	.....	.....	0.0000133	24	0.23
220–T4	0.093	9,500	3,550	0.0000137	21	0.21
319–F	0.101	10,700	4,000	0.0000119	27	0.26

See page 38 for footnotes.

Continued on next page

TABLE 3b

Typical Physical Properties—*Concluded*

CASTING ALLOYS

Alloy	Weight, Lb per Cu In.	Modulus of Elasticity, Kips per Sq In.		Coefficient of Thermal Expansion per Degree F①, 68° to 212°F	Electrical Conductivity, Per Cent of International Annealed Copper Standard	Thermal Conductivity at 25°C, CGS Units
		Tension and Compression	Shear			
333–F③	0.100	.....	.....	0.0000115	26	0.25
333–T5③	0.100	.....	.....	0.0000114	29	0.29
333–T6③	0.100	.....	.....	0.0000115	29	0.28
333–T7③	0.100	.....	.....	0.0000115	35	0.34
355–T51	0.098	10,200	3,800	0.0000124	43	0.40
355–T6	0.098	10,200	3,800	0.0000124	36	0.34
355–T6③	0.098	10,200	3,800	0.0000124	39	0.36
355–T61	0.098	10,200	3,800	0.0000124	37	0.34
355–T7	0.098	10,200	3,800	0.0000124	42	0.39
C355–T61	0.098	10,200	3,800	0.0000124	37	0.34
356–T51	0.097	10,500	3,950	0.0000119	43	0.40
356–T6	0.097	10,500	3,950	0.0000119	39	0.36
356–T6③	0.097	10,500	3,950	0.0000119	41	0.38
356–T7	0.097	10,500	3,950	0.0000119	40	0.37
A356–T61	0.097	10,500	3,950	0.0000119	41	0.38
360–F③	0.095	10,300	3,850	0.0000116	28	0.27
380–F③	0.098	10,300	3,850	0.0000116	23	0.23
384–F	0.098	10,300	3,850	0.0000113	23	0.23
A612–F	0.102	9,700	3,650	0.0000134	35	0.33
C612–F③	0.103	.....	.....	0.0000131	40	0.38
750–F③	0.104	10,300	3,850	0.0000130	46	0.43
A750–T5	0.103	10,300	3,850	0.0000126	43	0.40
B750–T5	0.104	10,300	3,850	0.0000129	45	0.42

①Values of coefficient of thermal expansion for "F" and "T" tempers may vary slightly from one casting to another.

②While castings are not commonly annealed, similar effects on conductivities may result from the slower rate of cooling of thick sections as compared with thin ones and other variables in foundry practices. Comparison of the values for as-cast and annealed specimens will show the extent to which variations may be expected, depending upon differences in thermal conditions in the production of different types of castings.

③Chill cast samples; all other samples cast in green sand molds.

EXPLANATION OF TABLE 4

Units

All strength values in Table 4 are expressed in kips per square inch. One kip is equal to one thousand pounds.

Dimensions

In many cases in Table 4 it is necessary to show thickness ranges or other dimensional classifications, since the minimum properties of the products vary with these factors. The dimensional ranges shown do not necessarily mean that items outside these ranges are not available. The nearest Alcoa sales office should be consulted for information on limiting sizes of products.

Minimum Values

Most of the tensile properties listed in Table 4 are guaranteed minimum values. The rest of the tensile properties, and also the other quantities in the table, are corresponding minimum expected values but are not guaranteed. Tables of minimum mechanical properties guaranteed by Alcoa are available in another publication, the *Alcoa Aluminum Handbook*.

In all cases the values in Table 4 are for metal at room temperature but may be considered applicable to temperatures from 0° to 150° F. For effects of temperature on properties, see Tables 8a, 8b and 8c, pages 76 to 82.

Wrought Products

Guaranteed minimum tensile properties of wrought products are based on test specimens taken from a specified location and direction in the part and do not necessarily represent the absolute minimum values that could be found anywhere in the part. However, for most design purposes, the guaranteed minimum tensile properties and the other corresponding minimum properties in Table 4 are satisfactory for use as over-all minimum values.

For all wrought products, the minimum tensile properties in Table 4 apply to the direction in which specified mechanical properties are determined. This is the principal direction of working (longitudinal direction) for all products except heat-treated sheet and plate. For heat-treated sheet and plate, specifications require that tensile properties be measured in the transverse direction, since these values are generally lower than the longitudinal properties.

Compressive yield strength values in Table 4 apply to the principal direction of working for all wrought products since compressive yield strength is generally lowest in this direction.

Die Forgings

It is customary to conduct quality control tensile tests for die forgings on separately forged coupons. Except for elongations, the properties so determined are applicable not only to the separately forged coupons but also to specimens that might be cut from the forgings themselves in a direction

substantially parallel to the grain flow. In the case of elongations, however, the die forgings will show lower values than the separately forged coupons, and in order to take account of this difference the elongations in Table 4h are seven-tenths those specified for the separately forged coupons.

Castings

Because of variations in size, shape and casting techniques, it is usually not practicable to give minimum properties for specimens cut from various locations in sand, permanent-mold and die castings. The properties shown in Tables 4j, 4k and 4m are representative of individually cast test bars, except as noted. Test specimens machined from the thickest, thinnest and medium parts of actual sand and permanent-mold castings usually exhibit strengths that average at least 75 per cent of those of the separately cast test bars. In view of these differences between the test-bar properties and those of the actual castings, it is customary to design castings somewhat more conservatively than wrought products.

Where a plus (+) is given in the elongation column, the minimum elongation is 1 per cent or less. These values are not specified because the error in determining elongations of 1 per cent or less is comparable with the value being measured.

The properties of 195-T4 castings will approach those of 195-T6 castings after several weeks of room temperature aging.

Tensile Properties

The tensile ultimate strength, tensile yield strength and elongation values are determined in accordance with ASTM Tentative Methods of Tension Testing of Metallic Materials E8-52T. The ASTM sheet-type and round-type specimens with 2-in. gage lengths are the principal ones employed. Yield strength is the stress that produces a permanent set of 0.2 per cent of the initial gage length. Elongation is given in per cent of gage length, the gage length being either 2 in. or, in the case of round specimens, four times the diameter of the reduced section of the specimen. Where an asterisk (*) is shown in the elongation column, it means that there is more than one minimum elongation for the thickness range and that the specified values are to be found in Tables 5a and 5b, pages 67 to 70.

Compressive Properties

Compressive yield strength is determined in accordance with ASTM Tentative Methods of Compression Testing of Metallic Materials, E9-52T, and is the stress that produces a permanent set of 0.2 per cent of the initial gage length. Compressive ultimate strength is not listed in Table 4 because the term has no meaning except for materials which fail by a shattering fracture. Ductile materials merely swell or buckle without fracture and hence do not exhibit a compressive ultimate strength.

Shear Properties

The shear ultimate strength is determined by conducting a double shear test in steel tools on a suitable solid cylindrical specimen in the case of thick materials, or by blanking out a circle in the case of sheet. The shear yield strength is the shear stress that produces a permanent shear deformation of 0.2 per cent of the gage length in a torsion test on a suitable specimen.

Bearing Properties

These properties apply to rivets, pins or bolts in tightly fitted holes where there is no rotation of the rivets, pins or bolts in the holes. They do not apply to a shaft turning against a surface. The values are established by applying load to a steel pin in a tightly fitted hole in a suitable test specimen with an edge distance equal to twice the diameter of the pin. Edge distance is defined as the distance from the center of the pin to the edge of the specimen toward which the pressure is directed.

The bearing ultimate strength is the ultimate load divided by the projected area of the hole. The projected area of the hole is determined as the product of the pin diameter and the thickness of the specimen. Bearing yield strength is the average stress on the projected area of the hole that produces a permanent set of 2 per cent of the hole diameter. Both bearing ultimate and bearing yield strength are influenced by edge distance, and the values given in Table 4 should be reduced as described in the design section of this handbook for those cases in which the edge distance is less than twice the diameter of the rivet, pin or bolt.

Alclad Material

All properties given in Table 4 for alclad material apply to the full thickness of the material including the cladding. This is in accordance with conventional practice in the case of material less than ½-in. thick, on which tensile tests are customarily conducted on full thickness material with the ASTM sheet-type specimen. On thicker material, tensile tests are customarily conducted on round specimens, which represent only the core material, but the values in Table 4 for such cases have been adjusted to represent the full thickness of the material including the cladding. Table 13, page 90, gives data on cladding thicknesses.

Buckling Formula Constants

The buckling formula constants given in Table 4 are to be used with the formulas on pages 111, 112 and 137 in the design section of this handbook to arrive at critical compression and shear buckling stresses. Buckling stresses calculated by the use of the constants in Table 4 apply to material having minimum mechanical properties.

TABLE 4a

Minimum Mechanical Properties and Buckling Formula Constants

SHEET AND PLATE

See page 39 for explanation of "minimum" properties.

US = ultimate strength in kips per sq in., YS = yield strength in kips per sq in., El = elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
1060–O	0.020–3.000	9.5	2.5	*	2.5	6.5	1.5	17	6	2.6	0.005	317	1.6	0.002	330
1060–H112	0.250–0.499	12	7	10	7	8	4	20	11	7.6	0.025	186	4.6	0.011	212
1060–H112	0.500–1.000	11	5	20	5	7.5	3	19	9	5.4	0.015	222	3.2	0.006	241
1060–H112	1.001–3.000	10	4	25	4	7	2.5	18	7	4.3	0.010	221	2.6	0.005	317
1060–H12	0.020–2.000	11	9	*	8	7.5	5	19	14	8.7	0.030	165	5.2	0.014	218
1060–H14	0.020–1.000	12	10	*	9	8	6	20	16	9.9	0.037	160	5.9	0.017	207
1100–O	0.006–3.000	11	3.5	*	3.5	8	2	23	8	3.7	0.008	239	2.2	0.003	271
1100–H112	0.250–0.499	13	7	9	7	8.5	4	26	13	7.6	0.025	186	4.6	0.011	212
1100–H112	0.500–2.000	12	5	14	5	8.5	3	24	10	5.4	0.015	222	3.2	0.006	241
1100–H112	2.001–3.000	11.5	4.5	20	4.5	8	2.5	23	9	4.8	0.012	213	2.9	0.005	248
1100–H12 or H22	0.017–2.000	14	11	*	10	9	6.5	27	18	11.0	0.043	149	6.6	0.020	193
1100–H14 or H24	0.009–1.000	16	14	*	13	10	8	29	23	14.5	0.066	135	8.7	0.030	165
1100–H16 or H26	0.006–0.162	19	17	*	16	11	10	32	26	18.0	0.092	128	10.8	0.042	152
1100–H18 or H28	0.006–0.128	22	20	*	18	12	11	35	30	20.4	0.111	121	12.2	0.051	148
Alclad 2014–O	0.020–1.000	22	8	*	8	15	4.5	46	19	8.7	0.030	165	5.2	0.014	218
Alclad 2014–T3	0.020–0.039	55	35	14	33	35	20	106	64	39.0	0.293	86	23.4	0.136	109
Alclad 2014–T3	0.040–0.249	57	36	15	34	37	21	110	66	40.3	0.308	85	24.2	0.143	107
Alclad 2014–T4	0.020–0.039	55	32	14	32	33	18	105	51	37.7	0.278	86	22.6	0.129	111
Alclad 2014–T4	0.040–0.249	57	34	15	34	34	20	108	54	40.3	0.308	85	24.2	0.143	107
Alclad 2014–T4	0.250–0.499	57	36	15	34	37	21	110	66	40.3	0.308	85	24.2	0.143	107
Alclad 2014–T4	0.500–1.000	55	34	15	32	34	20	106	59	37.7	0.278	86	22.6	0.129	111

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
Alclad 2014–T6	0.020–0.039	63	55	7	56	39	32	122	90	65.9	0.558	53	39.5	0.259	68
Alclad 2014–T6	0.040–0.499	64	57	8	58	39	33	124	93	68.5	0.592	52	41.1	0.275	67
Alclad 2014–T6	0.500–1.500	64	57	*	58	39	33	124	93	68.5	0.592	52	41.1	0.275	67
Alclad 2014–T6	1.501–2.000	62	57	3	58	38	33	118	91	68.5	0 592	52	41.1	0.275	67
Alclad 2014–T6	2.001–3.000	60	55	2	56	37	32	114	88	65.9	0.558	53	39.5	0.259	68
2024–O	0.010–1.750	24	8	*	8	15	4.5	50	19	8.7	0.030	165	5.2	0.014	218
2024–T3	0.010–0.249	64	42	*	40	40	24	124	77	48.0	0.400	77	28.8	0.186	100
2024–T36①	0.020–0.500	69	52	*	49	43	30	133	96	59.8	0.557	70	35.9	0.259	90
2024–T4	0.010–0.249	62	40	*	40	37	23	118	64	48.0	0.400	77	28.8	0.186	100
2024–T4	0.250–0.499	64	40	12	38	40	23	124	74	45.4	0.368	79	27.2	0.170	100
2024–T4	0.500–1.000	62	40	8	38	38	23	120	70	45.4	0.368	79	27.2	0.170	100
2024–T4	1.001–2.000	60	40	*	38	36	23	116	68	45.4	0.368	79	27.2	0.170	100
2024–T4	2.001–3.000	56	40	4	38	33	23	108	64	45.4	0.368	79	27.2	0.170	100
Alclad 2024–O	0.008–1.750	22	8	*	8	15	4.5	46	19	8.7	0.030	165	5.2	0.014	218
Alclad 2024–T3	0.010–0.062	59	39	*	37	38	23	114	73	44.1	0.352	80	26.5	0.164	103
Alclad 2024–T3	0.063–0.249	62	40	*	38	40	23	120	74	45.4	0.368	79	27.2	0.170	100
Alclad 2024–T36①	0.020–0.062	62	48	8	46	40	28	120	88	55.9	0.503	72	33.5	0.233	92
Alclad 2024–T36①	0.063–0.500	66	50	*	48	42	29	127	93	58.5	0.539	71	35.1	0.250	90

①Width up thru 48 in.

Continued on next page

TABLE 4a

Minimum Mechanical Properties and Buckling Formula Constants—*Continued*

SHEET AND PLATE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
Alclad 2024–T4	0.010–0.062	58	37	*	37	35	21	110	59	44.1	0.352	80	26.5	0.164	103
Alclad 2024–T4	0.063–0.128	61	38	15	38	37	22	116	61	45.4	0.368	79	27.2	0.170	100
Alclad 2024–T4	0.250–0.499	62	40	11	38	40	23	120	74	45.4	0.368	79	27.2	0.170	100
Alclad 2024–T4	0.500–1.000	60	38	8	36	37	22	116	67	42.8	0.337	82	25.7	0.157	108
Alclad 2024–T4	1.001–2.000	58	38	*	36	35	22	112	64	42.8	0.337	82	25.7	0.157	108
Alclad 2024–T4	2.001–3.000	54	38	4	36	32	22	103	61	42.8	0.337	82	25.7	0.157	108
Alclad 2024–T81	0.010–0.062	62	54	5	55	38	31	122	90	64.7	0.543	54	38.8	0.252	69
Alclad 2024–T81	0.063–0.499	65	56	5	57	39	32	127	94	67.2	0.575	53	40.3	0.267	68
Alclad 2024–T86①	0.020–0.062	66	62	3	63	40	36	133	104	74.9	0.677	50	44.9	0.314	64
Alclad 2024–T86②	0.063–0.249	70	66	4	66	41	38	135	109	78.7	0.729	49	47.2	0.338	63
3003–O	0.006–3.000	14	5	*	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003–H112	0.250–0.499	17	10	8	9	11	6	33	17	9.9	0.037	160	5.9	0.017	207
3003–H112	0.500–2.000	15	6	12	6	10.5	3.5	31	14	6.5	0.019	185	3.9	0.009	246
3003–H112	2.001–3.000	14.5	6	18	6	10.5	3.5	31	14	6.5	0.019	185	3.9	0.009	246
3003–H12 or H22	0.017–2.000	17	12	*	11	11	7	33	19	12.2	0.051	148	7.3	0.023	179
3003–H14 or H24	0.009–1.000	20	17	*	16	12	10	35	28	18.0	0.092	128	10.8	0.042	152
3003–H16 or H26	0.006–0.162	24	21	*	19	14	12	40	33	21.6	0.120	111	13.0	0.056	143
3003–H18 or H28	0.006–0.128	27	25	*	23	15	14	43	38	26.5	0.164	103	15.9	0.076	131

①Width up thru 48 in. ②Width up thru 30 in.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
Alclad 3003–O	0.006–3.000	13	4.5	*	4.5	9	2.5	28	11	4.8	0.012	213	2.9	0.005	248
Alclad 3003–H112	0.250–0.499	16	9	8	8	10	5	31	16	8.7	0.030	165	5.2	0.014	218
Alclad 3003–H112	0.500–2.000	14	5.5	12	5.5	9.5	3	29	13	5.9	0.017	207	3.5	0.007	234
Alclad 3003–H112	2.001–3.000	13.5	5.5	18	5.5	9.5	3	29	13	5.9	0.017	207	3.5	0.007	234
Alclad 3003–H12 or H22	0.017–2.000	16	11	*	10	10	6.5	31	17	11.0	0.043	149	6.6	0.020	193
Alclad 3003–H14 or H24	0.009–1.000	19	16	*	15	11	9	34	26	16.8	0.082	124	10.1	0.038	157
Alclad 3003–H16 or H26	0.006–0.162	23	20	*	18	13	11	39	32	20.4	0.111	121	12.2	0.051	148
Alclad 3003–H18 or H28	0.006–0.128	26	24	*	22	15	14	41	37	25.3	0.153	106	15.2	0.071	134
3004–O	0.006–3.000	22	8.5	*	8.5	14	5	46	20	9.3	0.034	171	5.6	0.015	196
3004–H112	0.250–3.000	23	9	7	9	14	5	48	21	9.9	0.037	160	5.9	0.017	207
3004–H32 or H22	0.017–2.000	28	21	*	19	15	12	59	33	21.6	0.120	111	13.0	0.056	143
3004–H34 or H24	0.009–1.000	32	25	*	23	17	14	67	40	26.5	0.164	103	15.9	0.076	131
3004–H36 or H26	0.006–0.162	35	29	*	28	19	17	73	47	32.7	0.225	94	19.6	0.104	118
3004–H38 or H28	0.006–0.128	38	31	*	30	20	18	80	50	35.2	0.251	89	21.1	0.116	113
Alclad 3004–O	0.006–3.000	21	8	*	8	13	4.5	44	18	8.7	0.030	165	5.2	0.014	218
Alclad 3004–H112	0.250–3.000	22	8.5	7	8.5	14	5	48	19	9.3	0.034	171	5.6	0.015	196
Alclad 3004–H32 or H22	0.017–0.249	27	20	*	18	15	12	57	32	20.4	0.111	121	12.2	0.051	148
Alclad 3004–H34 or H24	0.009–0.249	31	24	*	22	16	14	65	38	25.3	0.153	106	15.2	0.071	134
Alclad 3004–H36 or H26	0.006–0.162	34	28	*	27	18	16	71	45	31.4	0.212	98	18.8	0.098	123
Alclad 3004–H38 or H28	0.006–0.128	37	30	*	29	19	17	78	48	33.9	0.237	91	20.3	0.110	118
5005–O	0.006–3.000	14	5	*	5	9	3	...	...	5.4	0.015	222	3.2	0.006	241
5005–H12	0.017–2.000	17	14	*	13	12	8	...	...	14.5	0.066	135	8.7	0.030	165
5005–H14	0.009–1.000	20	17	*	16	12	10	...	...	18.0	0.092	128	10.8	0.042	152

Continued on next page

TABLE 4a

Minimum Mechanical Properties and Buckling Formula Constants—*Continued*

SHEET AND PLATE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5005-H16	0.006–0.162	24	21	*	19	14	12	...	...	21.6	0.120	111	13.0	0.056	143
5005-H18	0.006–0.128	27	24	*	22	15	14	...	...	25.3	0.153	106	15.2	0.071	134
5005-H32	0.017–2.000	17	12	*	11	12	7	...	...	12.2	0.051	148	7.3	0.023	179
5005-H34	0.009–1.000	20	15	*	14	12	8.5	...	...	15.7	0.074	128	9.4	0.034	162
5005-H36	0.006–0.162	23	18	*	17	13	10	...	...	19.2	0.101	120	11.5	0.047	163
5005-H38	0.006–0.128	26	21	*	19	14	12	...	...	21.6	0.120	111	13.0	0.056	143
5050-O	0.006–3.000	18	6	*	6	12	3.5	36	12	6.5	0.019	185	3.9	0.009	246
5050-H112	0.250–3.000	20	8	12	8	13	4.5	40	14	8.7	0.030	165	5.2	0.014	218
5050-H32	0.017–0.249	22	16	*	14	14	9	44	27	15.7	0.074	128	9.4	0.034	162
5050-H34	0.009–0.249	25	20	*	18	15	11	50	34	20.4	0.111	121	12.2	0.051	148
5050-H36	0.008–0.162	27	21	*	19	16	12	54	36	21.6	0.120	111	13.0	0.056	143
5050-H38	0.006–0.128	29	24	*	22	18	14	58	41	25.3	0.153	106	15.2	0.071	134
5052-O	0.006–3.000	25	9.5	*	9.5	16	5.5	50	19	10.4	0.040	159	6.2	0.018	194
5052-H112	0.250–0.499	28	16	7	15	16	9	56	27	16.8	0.082	124	10.1	0.038	157
5052-H112	0.500–3.000	25	9.5	*	9.5	16	5.5	50	16	10.4	0.040	159	6.2	0.018	194
5052-H32 or H22	0.017–2.000	31	23	*	21	19	13	62	39	24.0	0.141	107	14.4	0.065	134
5052-H34 or H24	0.009–1.000	34	26	*	24	20	15	68	44	27.7	0.175	100	16.6	0.081	128
5052-H36 or H26	0.006–0.162	37	30	*	27	22	17	74	51	31.4	0.212	98	18.8	0.098	123
5052-H38 or H28	0.006–0.128	39	33	*	30	23	19	78	56	35.2	0.251	89	21.1	0.116	113

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5083-O	0.051–2.000	40	18	16	18	25	10	80	36	20.4	0.111	121	12.2	0.051	148
5083-H113	0.126–2.000	44	31	12	29	26	18	80	50	33.9	0.237	91	20.3	0.110	118
5083-H321	0.126–2.000	44	31	12	29	26	18	80	50	33.9	0.237	91	20.3	0.110	118
5083-H323 or H32	0.051–0.249	45	34	*	32	26	20	85	54	37.7	0.278	86	22.6	0.129	111
5083-H343 or H34	0.051–0.249	50	39	*	37	29	22	95	62	44.1	0.352	80	26.5	0.164	103
5086-O	0.020–2.000	35	14	*	14	21	8	70	28	15.7	0.074	128	9.4	0.034	162
5086-H112	0.188–0.499	36	18	8	17	23	10	72	31	19.2	0.101	120	11.5	0.047	163
5086-H112	0.500–1.000	35	16	10	15	22	9	70	27	16.8	0.082	124	10.1	0.038	157
5086-H112	1.001–2.000	35	14	14	14	22	8	70	24	15.7	0.074	128	9.4	0.034	162
5086-H112	2.001–3.000	34	14	14	14	22	8	68	24	15.7	0.074	128	9.4	0.034	162
5086-H32	0.020–2.000	40	28	*	26	24	16	80	48	30.2	0.200	100	18.1	0.092	121
5086-H34	0.020–1.000	44	34	*	32	26	20	88	58	37.7	0.278	86	22.6	0.129	111
5086-H36	0.020–0.162	47	38	*	35	27	22	94	65	41.5	0.322	84	24.9	0.149	104
5154-O	0.020–3.000	30	11	*	11	19	6.5	60	22	12.2	0.051	148	7.3	0.023	179
5154-H112	0.250–0.500	32	18	8	17	19	10	64	31	19.2	0.101	120	11.5	0.047	163
5154-H112	0.501–3.000	30	11	*	11	19	6.5	60	19	12.2	0.051	148	7.3	0.023	179
5154-H32	0.020–2.000	36	26	*	24	21	15	72	44	27.7	0.175	100	16.6	0.081	128
5154-H34	0.020–1.000	39	29	*	27	23	17	78	49	31.4	0.212	98	18.8	0.098	123
5154-H36	0.020–0.162	42	32	*	29	24	18	84	54	33.9	0.237	91	20.3	0.110	118
5154-H38	0.020–0.128	45	35	*	32	26	20	90	60	37.7	0.278	86	22.6	0.129	111
5454-O	0.020–3.000	31	12	*	12	20	7	62	24	13.3	0.058	142	8.0	0.027	181
5454-H112	0.250–0.499	32	18	8	17	20	10	64	31	19.2	0.101	120	11.5	0.047	163
5454-H112	0.500–3.000	31	12	*	12	20	7	62	20	13.3	0.058	142	8.0	0.027	181
5454-H32	0.020–2.000	36	26	*	24	22	15	72	44	27.7	0.175	100	16.6	0.081	128
5454-H34	0.020–1.000	39	29	*	27	23	17	78	49	31.4	0.212	98	18.8	0.098	123

Continued on next page

TABLE 4a

Minimum Mechanical Properties and Buckling Formula Constants—*Concluded*

SHEET AND PLATE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5456-O	0.051–2.000	42	19	16	19	26	11	84	38	21.6	0.120	111	13.0	0.056	143
5456-H24	0.051–0.249	51	39	9	38	30	22	97	62	45.4	0.368	79	27.2	0.170	100
5456-H321	0.126–0.249	46	33	12	31	27	19	84	53	36.5	0.265	88	21.9	0.123	112
5456-H321	0.250–1.250	46	33	12	32	27	19	84	56	37.7	0.278	86	22.6	0.129	111
5456-H321	1.251–2.000	44	31	12	30	26	18	80	53	35.2	0.251	89	21.1	0.116	113
5456-H323 or H32	0.126–0.249	48	36	8	34	28	21	91	58	40.3	0.308	85	24.2	0.143	107
5456-H343 or H34	0.051–0.249	53	41	*	39	31	24	101	66	46.7	0.384	78	28.0	0.178	100
6061-O	0.010–3.000	16	6	*	6	11	3.5	33	15	6.5	0.019	185	3.9	0.009	246
6061-T4	0.010–3.000	30	16	*	16	20	9	63	26	18.0	0.092	128	10.8	0.042	152
6061-T6	0.010–3.000	42	35	*	35	27	20	88	58	39.9	0.263	68	23.9	0.122	88
Alclad 6061-O	0.010–0.500	16	6	*	6	11	3.5	33	15	6.5	0.019	185	3.9	0.009	246
Alclad 6061-T4	0.010–3.000	27	14	*	14	18	8	57	22	15.7	0.074	128	9.4	0.034	162
Alclad 6061-T6	0.010–3.000	38	32	*	32	24	14	80	51	36.3	0.228	71	21.8	0.106	92
7075-O	0.015–2.000	29	12	*	13	19	7	61	29	14.5	0.066	135	8.7	0.030	165
7075-T6	0.008–0.011	74	63	5	65	45	36	140	103	77.4	0.711	49	46.4	0.330	63
7075-T6	0.012–0.039	76	65	7	67	46	37	144	106	80.0	0.747	48	48.0	0.347	62
7075-T6	0.040–0.249	77	66	8	68	46	38	146	107	81.3	0.765	48	48.8	0.356	62
7075-T6	0.250–0.499	77	66	8	69	46	38	139	100	82.6	0.784	47	49.6	0.365	61
7075-T6	0.500–1.000	77	66	6	69	47	38	142	104	82.6	0.784	47	49.6	0.365	61
7075-T6	1.001–2.000	77	66	4	68	46	38	140	102	81.3	0.765	48	48.8	0.356	62
7075-T6	2.001–2.500	73	62	3	65	44	36	131	93	77.4	0.711	49	46.4	0.330	63
7075-T6	2.501–3.000	70	60	3	63	42	35	126	90	74.9	0.677	50	44.9	0.314	64
7075-T6	3.001–3.500	68	58	3	62	41	33	122	87	73.6	0.659	50	44.2	0.307	65
7075-T6	3.501–4.000	66	56	2	60	40	32	119	84	71.0	0.624	51	42.6	0.290	66

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
Alclad 7075-O	0.008–0.062	27	11	*	12	18	6.5	57	26	13.3	0.058	142	8.0	0.027	181
Alclad 7075-O	0.063–1.000	28	12	10	13	18	7	59	29	14.5	0.066	135	8.7	0.030	165
Alclad 7075-T6	0.008–0.011	68	58	5	60	41	34	129	95	71.0	0.624	51	42.6	0.290	66
Alclad 7075-T6	0.012–0.039	70	60	7	62	42	35	133	98	73.6	0.659	50	44.2	0.307	65
Alclad 7075-T6	0.040–0.062	72	62	8	64	43	36	137	101	76.1	0.693	49	45.7	0.322	64
Alclad 7075-T6	0.063–0.187	73	63	8	65	44	36	139	102	77.4	0.711	49	46.4	0.330	63
Alclad 7075-T6	0.188 0.249	75	64	8	66	45	37	142	104	78.7	0.729	49	47.2	0.338	63
Alclad 7075-T6	0.250 0.499	75	64	8	66	45	37	135	98	78.7	0.729	49	47.2	0.338	63
Alclad 7075-T6	0.500 1.000	75	64	6	66	46	37	139	99	78.7	0.729	49	47.2	0.338	63
Alclad 7075-T6	1.001–2.000	75	64	4	66	45	37	137	99	78.7	0.729	49	47.2	0.338	63
Alclad 7075-T6	2.001–2.500	71	60	3	62	42	35	128	90	73.6	0.659	50	44.2	0.307	65
Alclad 7075-T6	2.501–3.000	68	58	3	61	40	33	122	87	72.3	0.642	51	43.4	0.298	65
Alclad 7075-T6	3.001–3.500	66	56	3	60	39	32	119	84	71.0	0.624	51	42.6	0.290	66
Alclad 7075-T6	3.501–4.000	64	54	2	58	38	31	115	81	68.5	0.592	52	41.1	0.275	67
7178-T6	0.015–0.044	83	72	7	73	50	41	158	117	87.8	0.859	46	52.7	0.399	59
7178-T6	0.045–0.249	84	73	8	74	50	42	160	118	89.1	0.878	46	53.5	0.408	59
7178-T6	0.250 0.499	84	73	8	74	50	42	151	111	89.1	0.878	46	53.5	0.408	59
7178-T6	0.500–1.500	84	73	*	74	50	42	151	112	89.1	0.878	46	53.5	0.408	59
7178-T6	1.501–2.000	80	70	3	71	48	40	144	106	85.2	0.821	47	51.1	0.381	60
Alclad 7178-T6	0.015–0.044	76	66	7	67	46	38	144	107	80.0	0.747	48	48.0	0.347	62
Alclad 7178-T6	0.045–0.249	78	68	8	69	47	39	148	110	82.6	0.784	47	49.6	0.365	61
Alclad 7178-T6	0.250–0.499	78	68	8	69	47	39	140	104	82.6	0.784	47	49.6	0.365	61
Alclad 7178-T6	0.500–1.500	78	68	*	69	47	39	140	105	82.6	0.784	47	49.6	0.365	61
Alclad 7178-T6	1.501–2.000	75	65	3	66	45	37	135	99	78.7	0.729	49	47.2	0.338	63

TABLE 4b

Minimum Mechanical Properties and Buckling Formula Constants

EXTRUDED ROD, BAR AND SHAPES

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
2014-O	All	24	9	12	9	15	5	50	21	9.9	0.037	160	5.9	0.017	207
2014-T4	All	50	35	12	30	31	20	90	55	35.2	0.251	89	21.1	0.116	113
2014-T6	Up thru 0.499	60	53	7	55	35	31	114	85	61.4	0.410	50	36.8	0.190	64
2014-T6	0.500–0.749	64	58	7	60	37	33	122	93	67.3	0.471	48	40.4	0.219	62
2014-T6	0.750 and over Area 25 sq in. max.	68	60	7	62	39	35	109	84	69.7	0.496	47	41.8	0.230	61
	Area 25 to 32 sq in.	68	58	6	60	39	33	109	81	67.3	0.471	48	40.4	0.219	62
2024-O	All	25	9	12	9	15	5	52	21	9.9	0.037	160	5.9	0.017	207
2024-T4	Up thru 0.249	57	42	12	38	30	24	108	67	43.6	0.300	65	26.2	0.140	84
2024-T4	0.250–0.749	60	44	12	39	32	25	108	69	44.8	0.313	64	26.9	0.146	83
2024-T4	0.750–1.499	65	46	10	44	34	27	108	71	50.9	0.379	60	30.5	0.176	78
2024-T4	1.500–2.999 Area 25 sq in. max.	70	52	10	50	38	30	108	73	58.4	0.466	56	35.0	0.216	73
2024-T4	3.000 and over Area 25 sq in. max.	70	52	10	50	37	30	108	73	58.4	0.466	56	35.0	0.216	73
2024-T4	1.500 and over Area 25 thru 32 sq in.	68	48	8	46	36	28	108	72	53.4	0.407	59	32.0	0.189	76
3003-O	All	14	5	25	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003-H112	All	14	5	..	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
5083-O	All	38	16	16	..	..	..	...	..	....	.....	...	....	.....	...
5083-H112	All	40	24	12	..	..	..	...	..	....	.....	...	....	.....	...
5086-O	All	35	14	14	..	..	..	...	..	....	.....	...	....	.....	...
5086-H112	All	35	18	12	..	..	..	...	..	....	.....	...	....	.....	...

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5154–O	All	30	11	14	..	..	..	...	..	.....	.....	...	.....	.....	...
5154–H112	All	30	11	12	..	..	..	...	..	.....	.....	...	.....	.....	...
5454–O	Up to 5.000	31	12	14	12	..	..	...	..	13.3	0.058	142	8.0	0.027	181
5454–H111	All	34	21	12	..	..	..	...	..	.....	.....	...	.....	.....	...
5454–H112	Up to 5.000	31	12	12	12	..	..	...	..	13.3	0.058	142	8.0	0.027	181
5454–H311	Up to 5.000	33	20	12	18	19	11	59	34	20.4	0.111	121	12.2	0.051	148
5456–O	Up to 5.000③	42	19	16	19	..	..	...	..	21.6	0.120	111	13.0	0.056	143
5456–H111	Up to 5.000③	44	26	12	..	..	..	79	44	.....	.....	...	.....	.....	...
5456–H112	Up to 5.000③	42	19	12	19	..	..	...	..	21.6	0.120	111	13.0	0.056	143
5456–H311	Up to 5.000③	42	25	12	22	26	14	79	42	25.3	0.153	106	15.2	0.071	134
6061–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6061–T4	All	26	16	16	14	16	9	55	26	15.7	0.074	128	9.4	0.034	162
6061–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6061–T62	All	35	26	10	26	22	15	74	42	28.1	0.127	74	16.9	0.059	95
6062–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6062–T4	All	26	16	16	14	16	9	55	26	15.7	0.074	128	9.4	0.034	162
6062–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6062–T62	All	35	26	10	26	22	15	74	42	28.1	0.127	74	16.9	0.059	95
6063–T42	Up thru 0.500	17	10	12	10	11	6	36	16	11.0	0.043	149	6.6	0.020	193
6063–T5	Up thru 0.500	22	16	8	16	13	9	46	25	17.5	0.076	103	10.5	0.036	134
6063–T6	Up thru 0.124	30	25	8	25	19	14	63	40	28.0	0.155	81	16.8	0.072	105
6063–T6	0.125–0.500	30	25	10	25	19	14	63	40	28.0	0.155	81	16.8	0.072	105
7075–O	All	29	11	10	12	19	6.5	61	26	13.3	0.058	142	8.0	0.027	181
7075–T6	Up thru 0.249	78	70	7	70	43	40	125	98	79.3	0.602	44	47.6	0.280	57
7075–T6	0.250–0.499	81	73	7	73	45	42	130	102	87.8	0.859	46	52.7	0.399	59
7075–T6	0.500–1.499	82	73	7	73	45	42	131	102	87.8	0.859	46	52.7	0.399	59
7075–T6	1.500–2.999	81	72	7	72	45	42	130	101	81.7	0.629	43	49.0	0.292	56
7075–T6	3.000–4.499①	81	71	7	71	45	41	130	99	85.2	0.821	47	51.1	0.381	60
7075–T6	3.000–4.499②	78	70	6	70	43	40	125	98	79.3	0.602	44	47.6	0.280	57
7075–T6	4.500–5.000③	78	68	6	68	43	39	125	95	76.9	0.575	45	46.1	0.267	58
7178–T6	Up thru 0.249	84	76	5	76	45	44	134	106	86.5	0.686	42	51.9	0.319	54
7178–T6	0.250–2.999③	86	78	5	78	46	45	138	109	88.9	0.714	42	53.3	0.332	54

①Area up thru 20 sq. in. ②Area 20 thru 32 sq. in. ③Area up thru 32 sq. in.

TABLE 4c

Minimum Mechanical Properties and Buckling Formula Constants

STANDARD STRUCTURAL SHAPES—Rolled or Extruded

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
2014–O	All	24	9	12	9	15	5	50	21	9.9	0.037	160	5.9	0.017	207
2014–T4	All	50	32	12	30	31	18	90	51	35.2	0.251	89	21.1	0.116	113
2014–T6	All	60	53	7	55	35	31	114	85	64.7	0.543	54	38.8	0.252	69
5456–O	All	42	19	16	19	..	..	..	..	21.6	0.120	111	13.0	0.056	143
5456–H112	All	42	19	12	19	..	..	..	..	21.6	0.120	111	13.0	0.056	143
5456–H311	All	42	25	12	22	24	14	76	42	25.3	0.153	106	15.2	0.071	134
6061–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6061–T4	All	26	16	16	14	16	9	55	26	15.7	0.074	128	9.4	0.034	162
6061–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6061–T62	All	35	26	10	26	22	15	74	42	28.1	0.127	74	16.9	0.059	95
6062–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6062–T4	All	26	16	16	14	16	9	55	26	15.7	0.074	128	9.4	0.034	162
6062–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82

TABLE 4d

Minimum Mechanical Properties and Buckling Formula Constants

ROLLED AND COLD-FINISHED ROD AND BAR

See page 39 for explanation of "minimum" properties.

US = ultimate strength in kips per sq in., YS = yield strength in kips per sq in., El = elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Diameter or Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
EC-O	All	10	3	....	3	7	1.5	21	7	3.2	0.006	241	1.9	0.003	341
EC-H12	Up to 1 in.	12	8	....	8	8	4.5	24	13	8.7	0.030	165	5.2	0.014	218
EC-H13	Up to 1 in.	14	12	....	12	9	7	27	20	13.3	0.058	142	8.0	0.027	181
EC-H17	Up to ½ in.	17	15	....	15	10	8.5	30	24	16.8	0.082	124	10.1	0.038	157
1100-O	All	11	3.5	25	4	8	2	23	8	4.3	0.010	221	2.6	0.005	317
1100-F	0.375 and over	12	7	....	7	8.5	4	24	13	7.6	0.025	186	4.6	0.011	212
2011-T3	0.125–1.500	45	38	10	38	27	22	85	61	45.4	0.368	79	27.2	0.170	100
2011-T3	1.501–2.000	43	34	12	34	26	20	82	54	40.3	0.308	85	24.2	0.143	107
2011-T3	2.001–3.000	42	30	14	30	26	17	80	48	35.2	0.251	89	21.1	0.116	113
2011-T8	0.125–3.250	52	40	10	40	32	23	99	64	48.0	0.400	77	28.8	0.186	100
2014-O	Up thru 8.000	24	9	12	9	15	5	50	21	9.9	0.037	160	5.9	0.017	207
2014-T4	Up thru 6.750	55	32	16	32	33	18	105	51	37.7	0.278	86	22.6	0.129	111
2014-T6	Up thru 6.750	65	55	8	55	38	32	124	88	64.7	0.543	54	38.8	0.252	69
2017-O	Up thru 8.000	24	9	16	9	16	5	50	21	9.9	0.037	160	5.9	0.017	207
2017-T4	Up thru 8.000	55	32	16	32	33	18	105	51	37.7	0.278	86	22.6	0.129	111

Continued on next page

TABLE 4d

Minimum Mechanical Properties and Buckling Formula Constants—*Concluded*

ROLLED AND COLD-FINISHED ROD AND BAR

See page 39 for explanation of "minimum" properties.
US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.
See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Diameter or Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
2024-O	Up thru 8.000	25	9	16	9	17	5	52	21	9.9	0.037	160	5.9	0.017	207
2024-T4	Up thru 6.500	62	40	14	40	37	23	118	64	48.0	0.400	77	28.8	0.186	100
3003-O	All	14	5	25	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003-H12	Up thru 0.374	17	12	10	11	11	7	33	19	12.2	0.051	148	7.3	0.023	179
3003-H14	Up thru 0.313	20	17	10	15	13	10	35	28	16.8	0.082	124	10.1	0.038	157
3003-H16	Up thru 0.250	24	21	..	20	14	12	40	33	22.8	0.131	112	13.7	0.061	144
3003-H18	Up thru 0.204	27	25	..	23	15	14	43	38	26.5	0.164	103	15.9	0.076	131
5052-O	All	25	9.5	25	10	16	5.5	53	20	11.0	0.043	149	6.6	0.020	193
5052-F	0.375 and over	26	11	....	11	17	6.5	55	22	12.2	0.051	148	7.3	0.023	179
6061-O	Up thru 8.000	16	5	18	5	11	3	33	12	5.4	0.015	222	3.2	0.006	241
6061-T4	Up thru 8.000	30	16	18	16	20	9	63	26	18.0	0.092	128	10.8	0.042	152
6061-T6	Up thru 8.000	42	35	10	35	25	20	88	56	38.3	0.202	63	23.0	0.094	82
7075-O	Up thru 8.000	28	11	10	11	18	6.5	59	26	12.2	0.051	148	7.3	0.023	179
7075-T6	Up thru 4.000	77	66	7	66	46	38	123	92	78.7	0.729	49	47.2	0.338	63

TABLE 4e

Minimum Mechanical Properties and Buckling Formula Constants

PIPE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Size or Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
3003-O	All	14	5	....	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003-H112	1 in. and over	14.5	6	....	6	10	3.5	31	14	6.5	0.019	185	3.9	0.009	246
3003-H18	Under 1 in. size	27	24	....	23	15	14	43	38	26.5	0.164	103	15.9	0.076	131
3003-F	1 in. and over	14	5	....	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6061-T6	Under 1 in. size	42	35	12	35	27	20	88	56	38.3	0.202	63	23.0	0.094	82
6061-T6	1 in. and over	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6063-T5	All	22	16	10	16	13	9	46	25	17.5	0.076	103	10.5	0.036	134
6063-T6	All	30	25	8	25	19	14	63	40	28.0	0.155	81	16.8	0.072	105
6063-T832	All	38	35	5	35	23	20	80	56	38.3	0.202	63	23.0	0.094	82

TABLE 4f

Minimum Mechanical Properties and Buckling Formula Constants

EXTRUDED TUBE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Wall Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
2014–O	All	24	9	12	9	15	5	50	21	9.9	0.037	160	5.9	0.017	207
2014–T4	0.125–0.499	50	30	12	26	31	17	90	47	30.2	0.200	100	18.1	0.092	121
2014–T4	0.500 and over	55	35	12	30	34	20	99	55	35.2	0.251	89	21.1	0.116	113
2014–T6	0.125–0.499	60	53	7	55	35	31	114	85	61.4	0.410	50	36.8	0.190	64
2014–T6	0.500–0.749	64	58	7	60	37	33	122	93	67.3	0.471	48	40.4	0.219	62
2014–T6	0.750 and over—														
	Area 25 sq in. max.	68	60	7	62	39	35	114	84	69.7	0.496	47	41.8	0.230	61
	Area 25 to 32 sq in.	68	58	6	60	39	33	114	81	67.3	0.471	48	40.4	0.219	62
2024–O	All	25	9	12	9	15	5	52	21	9.9	0.037	160	5.9	0.017	207
2024–T4	0.499 and less	60	40	10	36	32	23	108	62	41.1	0.275	67	24.7	0.128	87
2024–T4	0.500–1.499	65	46	10	44	34	27	108	71	50.9	0.379	60	30.5	0.176	78
2024–T4	1.500 and over—														
	Area 25 sq in. max.	70	48	10	46	37	28	108	72	53.4	0.407	59	32.0	0.189	76
	Area 25 to 32 sq in.	68	46	6	44	36	27	108	71	50.9	0.379	60	30.5	0.176	78
3003–O	All	14	5	25	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003–F	All	14	5	....	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241

Alloy and Temper	Wall Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5154–O	All	30	11	14	11	19	6.5	63	23	12.2	0.051	148	7.3	0.023	179
6061–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6061–T4	All	26	16	16	14	16	9	54	25	15.7	0.074	128	9.4	0.034	162
6061–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6062–O	All	14	5	16	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
6062–T4	All	26	16	16	14	16	9	54	25	15.7	0.074	128	9.4	0.034	162
6062–T6	All	38	35	10	35	24	20	80	56	38.3	0.202	63	23.0	0.094	82
6063–T42	Up to 0.500	17	10	12	10	11	6	36	16	11.0	0.043	149	6.6	0.020	193
6063–T5	Up to 0.500	22	16	10	16	13	9	46	25	17.5	0.076	103	10.5	0.036	134
6063–T6	Up to 0.500	30	25	8	25	19	14	63	40	28.0	0.155	81	16.8	0.072	105
7075–O	All	29	11	10	12	19	6.5	61	26	13.3	0.058	142	8.0	0.027	181
7075–T6	Up to 0.249	78	70	7	70	43	40	125	98	79.3	0.602	44	47.6	0.280	57
7075–T6	0.250–2.999	80	72	7	72	44	42	128	101	81.7	0.629	43	49.0	0.292	56
7178–T6	Up to 0.249	84	76	5	76	45	44	134	106	86.5	0.686	42	51.9	0.319	54
7178–T6	0.250–2.999	86	78	5	78	46	45	138	109	88.9	0.714	42	53.3	0.332	54

TABLE 4g

Minimum Mechanical Properties and Buckling Formula Constants

DRAWN TUBE

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Wall Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
2024–O	All	24	8	....	8	15	4.5	50	19	8.7	0.030	165	5.2	0.014	218
2024–T3	0.018–0.500	64	42	*	42	39	24	122	67	50.6	0.433	75	30.4	0.202	100
3003–O	All	14	5	....	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003–H12	All	17	12	....	11	11	7	33	19	12.2	0.051	148	7.3	0.023	179
3003–H14	All	20	17	....	15	13	10	35	28	16.8	0.082	124	10.1	0.038	157
3003–H16	All	24	21	....	20	14	12	40	33	22.8	0.131	112	13.7	0.061	144
3003–H18	All	27	24	....	23	15	14	43	38	26.5	0.164	103	15.9	0.076	131
Alclad 3003–O	0.014–0.500	14	5	....	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
Alclad 3003–H12	0.014–0.500	17	12	....	11	11	7	33	19	12.2	0.051	148	7.3	0.023	179
Alclad 3003–H14	0.014–0.500	20	17	....	15	13	10	35	28	16.8	0.082	124	10.1	0.038	157
Alclad 3003–H16	0.014–0.500	24	21	....	20	14	12	40	33	22.8	0.131	112	13.7	0.061	144
Alclad 3003–H18	0.014–0.500	27	24	....	23	15	14	43	38	26.5	0.164	103	15.9	0.076	131
5050–O	All	18	6	....	6	12	3.5	38	14	6.5	0.019	185	3.9	0.009	246
5050–H34	All	25	20	....	18	15	11	49	32	20.4	0.111	121	12.2	0.051	148
5050–H38	All	29	24	....	22	18	14	54	38	25.3	0.153	106	15.2	0.071	134

Alloy and Temper	Wall Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
5052-O	All	25	10	16	10	16	6	53	21	11.0	0.043	149	6.6	0.020	193
5052-H34	All	34	26	....	23	20	15	71	38	26.5	0.164	103	15.9	0.076	131
5052-H38	All	39	31	....	29	23	18	82	51	33.9	0.237	91	20.3	0.110	118
6061-O	All	16	5	15	5	11	3	33	12	5.4	0 015	222	3.2	0.006	241
6061-T4	0.025–0.500	30	16	*	16	20	9	63	26	18.0	0.092	128	10.8	0.042	152
6061-T6	0.025–0.500	42	35	*	35	27	20	88	56	38.3	0.202	63	23.0	0.094	82
6062-O	All	16	5	15	5	11	3	33	12	5.4	0.015	222	3.2	0.006	241
6062-T4	0.025–0.500	30	16	*	16	20	9	63	26	18.0	0.092	128	10.8	0.042	152
6062-T6	0.025–0.500	42	35	*	35	27	20	88	56	38.3	0.202	63	23.0	0.094	82
6063-T83	All	33	30	5	30	20	17	69	48	32.6	0.159	69	19.6	0.074	88
6063-T831	All	28	25	5	25	17	14	59	40	27.0	0.120	75	16.2	0.056	97
6063-T832	All	40	35	5	35	24	20	84	56	38.3	0.202	63	23.0	0.094	82

TABLE 4h

Minimum Mechanical Properties and Buckling Formula Constants

DIE FORGINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
1100-F	Up to 4 in.	11	4	25	4	8	2.5	...	...	4.3	0.010	221	2.6	0.005	317
2014-T4	Up to 4 in.	55	30	11	30	34	17	105	48	35.2	0.251	89	21.1	0.116	113
2014-T6	Up to 4 in.	65	55	7	55	39	32	117	88	61.4	0.410	50	36.8	0.190	64
2018-T61	Up to 4 in.	55	40	7	40	35	23	105	64	48.0	0.400	77	28.8	0.186	100
2218-T61	Up to 4 in.	55	40	7	40	35	23	105	64	48.0	0.400	77	28.8	0.186	100
2218-T72	Up to 4 in.	38	29	6	29	24	17	72	46	33.9	0.237	91	20.3	0.110	118
3003-O	All	14	5	25	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
3003-F	All	14	5	..	5	10	3	30	12	5.4	0.015	222	3.2	0.006	241
4032-T6	Up to 4 in.	52	42	3	42	36	24	...	...	50.6	0.433	75	30.4	0.202	100
6061-T6	Up to 4 in.	38	35	7	35	25	20	80	56	38.3	0.202	63	23.0	0.094	82
6151-T6	Up to 4 in.	44	37	10	37	28	21	92	59	40.6	0.220	61	24.4	0.103	79
7075-T6	Up to 3 in.	75	65	7	65	45	37	120	97	73.3	0.535	46	44.0	0.249	59
7079-T6	Up to 6 in.	74	64	7	64	43	37	119	96	72.1	0.522	46	43.3	0.243	59

TABLE 4j

Minimum Mechanical Properties and Buckling Formula Constants

SAND CASTINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
43–F	The values to the right are based on tests of standard specimens individually cast. See page 41.	17	7	3	7	12	....	...	...	7.6	0.025	186	4.6	0.011	212
122–T61		30	28	+	30	22	....	...	...	35.2	0.251	89	21.1	0.116	113
142–T21		23	14	+	14	17	....	...	...	15.7	0.074	128	9.4	0.034	162
142–T571		29	26	+	30	23	....	...	...	35.2	0.251	89	21.1	0.116	113
142–T77		21.5	15	+	16	16	....	...	...	18.0	0.092	128	10.8	0.042	152
195–T4		29	13	6	14	22	....	61	26	15.7	0.074	128	9.4	0.034	162
195–T6		32	20	3	21	24	....	67	40	24.0	0.141	107	14.4	0.065	134
195–T62		36	28	+	29	28	....	76	56	33.9	0.237	91	20.3	0.110	118
195–T7		29	16	3	17	21	....	61	32	19.2	0.101	120	11.5	0.047	163
214–F		22	9	6	10	17	....	...	...	11.0	0.043	149	6.6	0.020	193
B214–F		17	10	+	11	13	....	...	...	12.2	0.051	148	7.3	0.023	179
F214–F		17	9	+	10	13	....	...	...	11.0	0.043	149	6.6	0.020	193

Continued on next page

TABLE 4j

Minimum Mechanical Properties and Buckling Formula Constants—*Concluded*

SAND CASTINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
220–T4	The values to the right are based on tests of standard specimens individually cast. See page 41.	42	22	12	23	30	....	88	44	26.5	0.164	103	15.9	0.076	131
319–F		23	14	+	17	18	....	...	...	19.2	0.101	120	11.5	0.047	163
319–T6		31	20	1.5	21	24	....	...	...	24.0	0.141	107	14.4	0.065	134
355–T51		25	18	+	18	19	....	...	...	20.4	0.111	121	12.2	0.051	148
355–T6		32	20	2	21	24	....	...	...	24.0	0.141	107	14.4	0.065	134
355–T61		36	31	+	33	28	....	...	...	39.0	0.293	86	23.4	0.136	109
355–T7		35	32	+	34	25	....	...	...	40.3	0.308	85	24.2	0.143	107
355–T71		30	22	+	23	21	....	...	...	26.5	0.164	103	15.9	0.076	131
356–T51		23	16	+	17	17	....	48	32	19.2	0.101	120	11.5	0.047	163
356–T6		30	20	3	20	25	....	63	40	22.8	0.131	112	13.7	0.061	144
356–T7		31	26	+	27	21	....	65	52	31.4	0.212	98	18.8	0.098	123
356–T71		25	18	3	19	17	....	52	36	21.6	0.120	111	13.0	0.056	143
A612–F		32	20	2	21	22	....	...	...	24.0	0.141	107	14.4	0.065	134
A750–T5		17	..	3	..	..	....	...	...	....	.....	...	....	.....	...

TABLE 4k

Minimum Mechanical Properties and Buckling Formula Constants

PERMANENT-MOLD CASTINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
43–F	The values to the right are based on tests of standard specimens individually cast. See page 41.	21	7	5	7	15	....	...	...	7.6	0.025	186	4.6	0.011	212
C113–F		25	20	+	21	20	....	...	...	24.0	0.141	107	14.4	0.065	134
122–T551		30	28	+	32	24	....	...	...	37.7	0.278	86	22.6	0.129	111
122–T65		40	30	+	30	30	....	...	...	35.2	0.251	89	21.1	0.116	113
F132–T5		31	..	+	..	..	..	...	...	.....	.....	...	.....	.....	...
142–T571		34	29	+	29	26	....	...	...	33.9	0.237	91	20.3	0.110	118
142–T61		40	36	+	37	30	....	...	...	44.1	0.352	80	26.5	0.164	103

Continued on next page

TABLE 4k

Minimum Mechanical Properties and Buckling Formula Constants—*Concluded*

PERMANENT-MOLD CASTINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
B195–T4	The values to the right are based on tests of standard specimens individually cast. See page 41.	33	15	4.5	15	25	....	59	27	16.8	0.082	124	10.1	0.038	157
B195–T6		35	22	2	22	26	....	63	40	25.3	0.153	106	15.2	0.071	134
B195–T7		33	16	3	16	25	....	59	29	18.0	0.092	128	10.8	0.042	152
A214–F		22	12	2.5	13	18	....	...	...	14.5	0.066	135	8.7	0.030	165
333–F		28	16	+	16	22	....	...	...	18.0	0.092	128	10.8	0.042	152
333–T5		30	22	+	22	24	....	...	...	25.3	0.153	106	15.2	0.071	134
333–T6		35	25	+	25	28	....	...	...	29.0	0.188	100	17.4	0.087	125
333–T7		31	23	+	23	23	....	...	...	26.5	0.164	103	15.9	0.076	131
355–T51		27	22	+	22	22	....	...	...	25.3	0.153	106	15.2	0.071	134
355–T6		37	23	1.5	23	26	....	...	...	26.5	0.164	103	15.9	0.076	131
355–T62		42	37	+	37	34	....	...	...	44.1	0.352	80	26.5	0.164	103
355–T7		36	27	+	27	27	....	...	...	31.4	0.212	98	18.8	0.098	123
355–T71		34	27	+	27	26	....	...	...	31.4	0.212	98	18.8	0.098	123
C355–T61①		37	30	1	30	26	..	...	...	35.2	0.251	89	21.1	0.116	113

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
356–T6		33	22	3	22	25	....	59	40	25.3	0.153	106	15.2	0.071	134
356–T7	The values to the	29	21	4	21	22	....	52	38	24.0	0.141	107	14.4	0.065	134
A356–T61①	right are based on	33	27	3	27	23	....	...	...	31.4	0.212	98	18.8	0.098	123
C612–F	tests of standard specimens individually cast.	28	14	7	14	21	....	...	...	15.7	0.074	128	9.4	0.034	162
750–T5	See page 41.	18	8	8	8	12	....	...	...	8.7	0.030	165	5.2	0.014	218
B750–T5		27	..	3	..	..	....	...	...	....	.....	...	....	.....	...

①The values shown for this alloy are valid for any location in the casting. See page 41.

TABLE 4m

Minimum Mechanical Properties and Buckling Formula Constants

DIE CASTINGS

See page 39 for explanation of "minimum" properties.

US=ultimate strength in kips per sq in., YS=yield strength in kips per sq in., El=elongation in per cent in 2 in. or 4 dia.

See pages 39 to 41 for definitions, methods of determination and notes.

Alloy and Temper	Thickness, In.	Minimum Mechanical Properties								Buckling Formula Constants					
		Tension			Compression	Shear		Bearing		Compression			Shear		
		US	YS	El	YS	US	YS	US	YS	B	D	C	B_1	D_1	C_1
218-F	The values to the right are based on tests of standard specimens individually cast. See page 41.	40	23	....	18	25	....	60	41	....	.....	...	....	.....	...
360-F		38	22	....	18	24	....	64	44	....	.....	...	....	.....	...
380-F		39	22	....	18	25	....	...	...	....	.....	...	....	.....	...

TABLE 5a

Minimum Elongation Values

Specified for SHEET AND PLATE (Alloys 1060, 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5005, 5050, 5052, 5083, 5086, 5154, 5454 and 5456)

Alloy and Temper	Minimum Elongation, Per Cent in 2 In.												
	Thickness, In.												
	3.000–2.001	2.000–1.001	1.000–0.500	0.499–0.250	0.249–0.162	0.161–0.129	0.128–0.114	0.113–0.051	0.050–0.032	0.031–0.020	0.019–0.013	0.012–0.008	0.007–0.006
1060–O	25	25	25	25	25	25	25	25	22	22	..	..	..
1060–H112	..	12	12	12	12	12	12	12	6	6	..	..	..
1060–H14	..	..	10	10	10	10	10	10	5	5	..	..	..
1100–O	28	28	28	28	30	30	30	30	25	20	15	15	15
1100–H12 or H22	..	12	12	9	9	9	9	8	6	4	3	..	..
1100–H14 or H24	..	..	10	6	6	6	6	5	4	3	2	1	..
1100–H16 or H26	..	..	..	..	..	4	4	4	3	2	1	1	1
1100–H18 or H28	..	..	..	..	..	..	4	4	3	2	1	1	1
3003–O	23	23	23	23	25	25	25	25	23	20	20	18	14
3003–H12 or H22	..	10	10	9	8	7	7	6	5	4	3	..	..
3003–H14 or H24	..	..	10	8	7	6	6	5	4	3	2	1	..
3003–H16 or H26	..	..	..	..	..	4	4	4	3	2	1	1	1
3003–H18 or H28	..	..	..	..	..	..	4	4	3	2	1	1	1
Alclad 3003–O	23	23	23	23	25	25	25	25	23	20	20	18	14
Alclad 3003–H12 or H22	..	10	10	9	8	7	7	6	5	4	4	..	..
Alclad 3003–H14 or H24	..	..	10	8	7	6	6	5	4	3	2	1	..
Alclad 3003–H16 or H26	..	..	..	..	..	4	4	4	3	2	1	1	1
Alclad 3003–H18 or H28	..	..	..	..	..	..	4	4	3	2	1	1	1
3004–O	16	16	16	16	18	18	18	18	16	14	10	10	..
3004–H32 or H22	..	6	6	6	6	6	6	5	4	3	1	..	..
3004–H34 or H24	..	..	5	5	5	5	5	4	3	3	1	1	..
3004–H36 or H26	..	..	..	..	..	4	4	4	3	2	1	1	..
3004–H38 or H28	..	..	..	..	..	..	4	4	3	2	1	1	..
Alclad 3004–O	16	16	16	16	18	18	18	18	16	14	10	10	..
Alclad 3004–H32 or H22	..	..	..	..	6	6	6	5	4	3	1	..	..
Alclad 3004–H34 or H24	..	..	..	..	5	5	5	4	3	3	1	1	..
Alclad 3004–H36 or H26	..	..	..	..	..	4	4	4	3	2	1	1	..
Alclad 3004–H38 or H28	..	..	..	..	..	..	4	4	3	2	1	1	..

Continued on next page

TABLE **5a**

Minimum Elongation Values—*Concluded*

Specified for SHEET AND PLATE (Alloys 1060, 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5005, 5050, 5052, 5083, 5086, 5154, 5454 and 5456)

Alloy and Temper	Minimum Elongation, Per Cent in 2 In.												
	Thickness, In.												
	3.000–2.001	2.000–1.001	1.000–0.500	0.499–0.250	0.249–0.162	0.161–0.129	0.128–0.114	0.113–0.051	0.050–0.032	0.031–0.020	0.019–0.013	0.012–0.008	0.007–0.006
5005–O	22	22	22	22	24	24	24	22	22	20	18	16	14
5005–H12	..	10	10	9	8	7	7	6	4	3	2	..	..
5005–H14	..	..	10	8	6	5	5	4	3	2	1	1	..
5005–H16	..	..	..	..	..	4	4	4	3	2	1	1	1
5005–H18	..	..	..	..	..	..	3	3	2	1	1	1	1
5005–H32	..	10	10	10	9	8	8	7	5	4	3	..	..
5005–H34	..	..	10	8	7	6	6	5	4	3	3	2	..
5005–H36	..	..	..	..	..	4	4	4	4	3	2	2	1
5005–H38	..	..	..	..	..	..	4	4	4	3	2	1	1
5050–O	20	20	20	20	22	22	22	20	20	18	16	16	..
5050–H32	..	..	..	..	6	6	6	6	4	4	4	..	..
5050–H34	..	..	..	..	5	5	5	5	4	3	3	3	..
5050–H36	..	..	..	..	..	4	4	4	3	3	2	2	..
5050–H38	..	..	..	..	..	..	4	4	3	2	2	2	..
5052–O	18	18	18	18	20	20	20	20	20	18	15	15	..
5052–H112	16	12	12	7	..	..	..	..	..	..	..	..	..
5052–H32	..	12	12	11	9	9	9	7	5	5	4	..	..
5052–H34	..	..	10	10	7	7	7	6	4	4	3	3	..
5052–H36	..	..	..	..	..	4	4	4	4	3	3	3	..
5052–H38	..	..	..	..	..	..	4	4	4	3	3	3	..
5083–H323 or H32	..	..	..	..	10	10	8	8	..	..	..	..	..
5083–H343 or H34	..	..	..	..	8	8	6	6	..	..	..	..	..
5086–O	..	14	14	14	18	18	18	18	15	15	..	..	..
5086–H32	..	12	12	12	8	8	8	8	6	6	..	..	..
5086–H34	..	..	10	10	6	6	6	6	5	5	..	..	..
5086–H36	..	..	..	..	..	6	6	6	4	4	..	..	..
5154–O	18	18	18	18	18	18	18	16	14	12	..	..	..
5154–H112	15	11	11	8	..	..	..	..	..	..	..	..	..
5154–H32	..	12	12	12	8	8	8	8	5	5	..	..	..
5154–H34	..	..	10	10	7	6	6	6	4	4	..	..	..
5154–H36	..	..	..	..	..	5	5	4	3	3	..	..	..
5154–H38	..	..	..	..	..	..	5	4	3	3	..	..	..
5454–O	18	18	18	18	16	16	16	16	14	12	..	..	..
5454–H112	15	11	11	8	..	..	..	..	..	..	..	..	..
5454–H32	..	12	12	12	8	8	8	8	5	5	..	..	..
5454–H34	..	..	10	10	7	6	6	6	4	4	..	..	..
5456–H343 or H34	..	..	..	..	8	8	6	6	..	..	..	..	..

TABLE 5b

Minimum Elongation Values

Not Listed in Tables 4 or 5a

(Given in Per Cent in 2 In. or 4d)

Alloy and Temper	Thickness, In.	Elongation
Sheet and Plate		
Alclad 2014–O	0.020–0.499	16
	0.500–1.000	10
Alclad 2014–T6	0.500–1.000	6
	1.001–1.500	4
2024–O	0.010–0.499	12
	0.500–1.750	8
2024–T3	0.010–0.020	12
	0.021–0.051	15
	0.052–0.128	17
	0.129–0.249	15
2024–T36	0.020–0.062	8
	0.063–0.499	9
	0.500	10
2024–T4	0.010–0.020	12
	0.021–0.051	15
	0.052–0.128	17
	0.129–0.249	15
	1.001–1.500	7
	1.501–2.000	6
Alclad 2024–O	0.008–0.009	7
	0.010–0.032	8
	0.033–0.062	10
	0.063–0.499	12
	0.500–1.750	8
Alclad 2024–T3	0.010–0.020	12
	0.021–0.128	15
	0.129–0.249	13
Alclad 2024–T36	0.063–0.499	9
	0.500	10
Alclad 2024–T4	0.010–0.020	12
	0.021–0.062	15
	1.001–1.500	7
	1.501–2.000	6

Alloy and Temper	Thickness, In.	Elongation
Sheet and Plate		
6061–O	0.010–0.020	14
	0.021–0.128	16
	0.129–1.000	18
	1.001–3.000	16
6061–T4	0.010–0.020	14
	0.021–0.249	16
	0.250–1.000	18
	1.001–3.000	16
6061–T6	0.010–0.020	8
	0.021–0.499	10
	0.500–1.000	9
	1.001–2.000	8
	2.001–3.000	6
Alclad 6061–O	0.010–0.020	14
	0.021–0.128	16
	0.129–0.500	18
Alclad 6061–T4	0.010–0.020	14
	0.021–0.249	16
	0.250–0.500	18
	0.501–1.000	17
	1.001–3.000	15
Alclad 6061–T6	0.010–0.020	8
	0.021–0.500	10
	0.501–1.000	9
	1.001–2.000	8
	2.001–3.000	6
7075–O	0.008–0.014	9
	0.015–2.000	10
Alclad 7075–O	0.008–0.014	9
	0.015–0.062	10
7178–T6	0.500–1.000	6
	1.001–1.500	4
Alclad 7178–T6	0.500–1.000	6
	1.001–1.500	4

Continued on next page

TABLE 5b

Minimum Elongation Values—*Concluded*

Not Listed in Tables 4 or 5a

(Given in Per Cent in 2 In. or 4d)

Alloy and Temper	Thickness, In.	Elongation
Drawn Tube		
2024–T3		
Full section specimen	0.018–0.024	10
	0.025–0.049	12
	0.050–0.259	14
	0.260–0.500	16
2024–T3		
Cut out specimen	0.025–0.259	10
	0.260–0.500	12
6061–T4, 6062–T4		
Full section specimen	0.025–0.049	16
	0.050–0.259	18
	0.260–0.500	20
Drawn Tube		
6061–T4, 6062–T4		
Cut out specimen	0.025–0.049	14
	0.050–0.259	16
	0.260–0.500	18
6061–T6, 6062–T6		
Full section specimen	0.025–0.049	10
	0.050–0.259	12
	0.260–0.500	14
6061–T6, 6062–T6		
Cut out specimen	0.025–0.049	8
	0.050–0.259	10
	0.260–0.500	12

TABLE 6a

ASTM Specification Numbers and Alloy Designations

WROUGHT PRODUCTS

Alloy	ASTM Specification Number for Various Products								ASTM Alloy Designation②
	Sheet and Plate	Rolled Rod and Bar	Rolled or Extruded Structural Shapes	Extruded Rod, Bar, Shapes	Extruded Tube	Drawn Tube		Pipe	
						General	Heat Exchangers		
EC	.....	B236	.....	.....	.....	.....	.....	.....	EC
1060	.....	.....	.....	.....	.....	.....	.....	.....	996A
1100	B209	B211①	.....	B221	.....	.....	.....	.....	990A
2011	.....	B211①	.....	.....	.....	.....	.....	.....	CB60A
2014	.....	B211①	B308	B221	B235	.....	.....	.....	CS41A
Alclad 2014	B209	.....	.....	.....	.....	.....	.....	.....	Clad CS41A
2017	.....	B211①	.....	.....	.....	.....	.....	.....	CM41A
2024	B209	B211①	.....	B221	B235	B210	.....	.....	CG42A
Alclad 2024	B209	.....	.....	.....	.....	.....	.....	.....	Clad CG42A
3003	B209	.....	.....	B221	B235	B210	B234①	B241	M1A
Alclad 3003	.....	.....	.....	.....	.....	.....	B234①	.....	Clad M1A
3004	B209	.....	.....	.....	.....	B210	.....	.....	MG11A
5005	B209	.....	.....	.....	.....	.....	.....	.....	G1B
5050	B209	.....	.....	.....	.....	.....	.....	.....	G1A
5052	B209	B211①	.....	.....	.....	B210	.....	.....	GR20A
5086	B209	.....	.....	.....	.....	.....	.....	.....	GM40A
5154	B209	.....	.....	B221	.....	.....	.....	.....	GR40A
5456	B209	.....	B308	B221	.....	.....	.....	.....	GM51A
6053	.....	.....	.....	B221	.....	.....	.....	.....	GS11B
6061	B209	B211①	B308	B221	B235	B210	.....	B241	GS11A
Alclad 6061	B209	.....	.....	.....	.....	.....	.....	.....	Clad GS11A
6062	.....	.....	B308	B221	.....	B210	.....	B241	GS11C
6063	.....	.....	.....	B221	B235	.....	.....	B241	GS10A
7075	B209	B211①	.....	B221	B235	.....	.....	.....	ZG62A
Alclad 7075	B209	.....	.....	.....	.....	.....	.....	.....	Clad ZG62A

①These same numbers and designations are used in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code except that the letter "S" is used in front of the specification number. Thus, ASTM specification B178 becomes ASME specification SB178.

②For explanation of these designations, see ASTM specification B275-52T.

TABLE 6b

ASTM Specification Numbers and Alloy Designations

CAST PRODUCTS

Alloy	ASTM Specification Number			ASTM Alloy Designation①
	Type of Casting			
	Sand	Permanent-Mold	Die	
13	....	....	B85	S12B
43	B26	B108	....	S5A
122	B26	B108	....	CG100A
142	B26	B108	....	CN42A
195	B26	.....	....	C4A
B195	....	B108	....	CS42A
214	B26	.....	....	G4A
A214	....	B108	....	GZ42A
B214	B26	B108	....	GS42A
218	....	.....	B85	G8A
220	B26	.....	....	G10A
319	B26	B108	....	SC64C
355	B26	B108	....	SC51A
356	B26	B108	....	SG70A
360	....	.....	B85	SG100B
380	....	.....	B85	SC84B

①For explanation of these designations, see ASTM specification B275-52T.

TABLE 7a

Thermal Treatment

Recommended Treatment for WROUGHT ALLOYS

Alloy	Annealing Treatment			Solution Heat Treatment①②		Precipitation Heat Treatment		
	Metal Temp., °F	Approx. Time of Heating, Hr	Temper Designation	Metal Temp., °F③	Temper Designation④	Metal Temp., °F③	Approx. Time of Heating, Hr⑤	Temper Designation④
1100	650	⑨	1100–O	....	.....	....	.....	.....
2011	775⑦	2–3	2011–O	950	2011–T4	320	12–16	2011–T6
2014⑥	775⑦	2–3	2014–O	940	2014–T4⑪	340	8–12	2014–T6⑱
2017	775⑦	2–3	2017–O	940	2017–T4	....	.....	.....
2018	775⑦	2–3	2018–O	950	2018–T4	340	8–12	2018–T61
2024⑥	775⑦	2–3	2024–O	920	2024–T4⑪	375⑫ 375⑫	11–13⑭ 7–9	2024–T81 2024–T84 2024–T86
2025	775⑦	2–3	2025–O	960	2025–T4	340	8–12	2025–T6
2117	775⑦	2–3	2117–O	940	2117–T4	....	.....	.....
2218	775⑦	2–3	2218–O	950	2218–T4	460	5–8	2218–T72
3003	775	⑨	3003–O	....	.....	....	.....	.....
3004	650	⑨	3004–O	....	.....	....	.....	.....
4032	775⑦	2–3	4032–O	950	4032–T4	340	8–12	4032–T6
4043	650	⑨	4043–O	....	.....	....	.....	.....
5005	650	⑨	5005–O	....	.....	....	.....	.....
5050	650	⑨	5050–O	....	.....	....	.....	.....
5052	650	⑨	5052–O	....	.....	....	.....	.....
5083	775	⑯	5083–O	....	.....	....	.....	.....
5086	775	⑨	5086–O	....	.....	....	.....	.....
5154	650	⑨	5154–O	....	.....	....	.....	.....
5454	775	⑨	5454–O	....	.....	....	.....	.....
5456	775	⑯	5456–O	....	.....	....	.....	.....
6053	775⑦	2–3	6053–O	970	6053–T4	450 350	1–2 6–8	6053–T5 6053–T6
6061	775⑦	2–3	6061–O	970	6061–T4	320 350	16–20 6–10	6061–T6
6062	775⑦	2–3	6062–O	970	6062–T4	350	6–10	6062–T6
6063	....	.....	.....	....	.....	450 350	1–2 6–8	6063–T5 6063–T6
6151	775⑦	2–3	6151–O	960	6151–T4	340	8–12	6151–T6
7072	650	⑨	7072–O	....	.....	....	.....	.....
7075⑥	775⑧	2–3	7075–O	870⑩	7075–W	250⑬	24–28	7075–T6
7079	775⑧	2–3	7079–O	830	7079–W	240	48	7079–T6
7178	775⑧	2–3	7178–O	870	7178–W	250	24–28	7178–T6

See page 74 for footnotes.

Table 7a—Footnotes

①The time of heating varies with the product, the type of furnace and the size of load. For sheet heat treated in a bath of molten salt, the time may range from 10 minutes for thin material to 60 minutes for thick material. Times of several hours may be required in air furnaces because the metal comes to temperature less rapidly. A minimum of 4 hours is suggested for average forgings. When heat treating in air furnaces, it may be desirable to use Alcoa Protective Compound to prevent oxidation along the grain boundaries in certain alloys.

②The material should be quenched from the solution heat-treating temperature as rapidly as possible and with a minimum of delay after removal from the furnace. Quenching in a large tank of cold water is preferred, although bulky sections, such as large forgings, usually are quenched in water at 140°F to 212°F (140°F to 160°F for 7075 forgings) to minimize quenching strains.

③The temperature specified should be attained by all portions of the load as rapidly as possible and should be maintained, with as little variation as possible, during the recommended time at temperature. Furnaces capable of maintaining the temperature well within plus or minus 10°F of that desired are readily available.

④These designations apply to material which has been heat treated by the user. A different designation may apply to material heat treated by the producer.

⑤The rate of cooling from the precipitation heat treatment is unimportant but should not be unduly slow.

⑥Alclad sheet is heat treated under the same conditions as the core alloy but the shortest heat-treatment time consistent with securing the required properties should be used, and repeated reheat treatments should be avoided. Prolonged heating or repeated reheat treatments cause diffusion of alloying elements into the coating and impair the resistance to corrosion.

⑦This treatment is intended to remove the effect of heat treatment and includes cooling at a rate of about 50°F per hour from the annealing temperature to 500°F. The rate of subsequent cooling is unimportant. The treatment recommended for 1100 can be used to remove the effects of cold work or partially to remove the effect of heat treatment if a completely annealed material is not required.

⑧Should be followed by heating for about 6 hours at about 450°F if material is to be stored for an extended period of time before use.

⑨Time in the furnace need not be longer than is necessary to bring all parts of the load to the annealing temperature. Cooling rate is unimportant.

⑩Sheet may also be heat treated at higher temperatures (up to 925°F) if desired.

⑪For extrusions, reheat treated by the user, the correct temper designation is T42. (See note 4 above.)

⑫Cold-working subsequent to the solution heat treatment and prior to the precipitation treatment is necessary to secure the required properties.

⑬Two-stage treatments comprising 4 to 6 hours at 210°F followed by 8 to 10 hours at 315°F or 2 to 4 hours at 250°F followed by 2½ to 3½ hours at 325°F may be used for sheet or for cold-drawn wire.

⑭For extrusions, a time of 6 hours should be used.

⑮For extrusions, reheat treated by the user, the correct temper designation is T62. (See note 4 above.)

⑯Slow cooling at 25°-50°F per hour from the annealing temperature is recommended.

TABLE 7b

Thermal Treatment

Recommended Treatment for CASTING ALLOYS

Alloy and Final Temper	Sand Castings				Permanent-Mold Castings			
	Solution Heat Treatment①		Precipitation Heat Treatment		Solution Heat Treatment①		Precipitation Heat Treatment	
	Temp., °F②	Time, Hr③	Temp., °F②	Time, Hr③	Temp., °F②	Time, Hr③	Temp., °F②	Time, Hr③
122–T551	.....	....	.....	.....	.....	....	340	18–22
122–T61	950	12	310	10–14	.....	....	.....	.....
122–T65	.....	....	.....	.....	950	8	340	7–9
F132–T5	.....	....	.....	.....	.....	....	400	7–9
142–T21	.....	....	650	2–4	.....	....	.....	.....
142–T571	.....	....	340	22–26	.....	....	340	22–26
142–T61	.....	....	.....	.....	960	6	400	3–5
142–T77①	960	6	650	1–3	.....	....	.....	.....
195–T4	960	12	.....	.....	.....	....	.....	.....
195–T6	960	12	310	3–6	.....	....	.....	.....
195–T62	960	12	310	12–20	.....	....	.....	.....
B195–T4	.....	....	.....	.....	950	8	.....	.....
B195–T6	.....	....	.....	.....	950	8	310	5–7
B195–T7	.....	....	.....	.....	950	8	500	4–6
319–T6	940	12	310	2–5	.....	....	.....	.....
333–T5	.....	....	.....	.....	.....	....	400	7–9
333–T6	.....	....	.....	.....	940	8	310	2–5
333–T7	.....	....	.....	.....	940	8	500	4–6
355–T51	.....	....	440	7–9	.....	....	440	7–9
355–T6	980	12	310	3–5	980	8	310	3–5
355–T61	980	12	310	8–10	.....	....	.....	.....
355–T62	.....	....	.....	.....	980	8	340	14–18
355–T7	980	12	440	7–9	980	8	440	7–9
355–T71	980	12	475	4–6	980	8	475	4–6
C355–T61	.....	....	.....	.....	980	8	310	10–12
C355–T62	.....	....	.....	.....	980	8	340	14–18
356–T51	.....	....	440	7–9	.....	....	.....	.....
356–T6	1000	12	310	3–5	1000	8	310	3–5
356–T7	1000	12	440	7–9	1000	8	440	7–9
356–T71	1000	12	475	2–4	.....	....	.....	.....
A356–T6	.....	....	.....	.....	1000	8	310	2–3
A356–T61	.....	....	.....	.....	1000	8	310	4–6
750–T5	.....	....	430	7–9	.....	....	430	7–9
A750–T5	.....	....	430	7–9	.....	....	430	7–9
B750–T5	.....	....	430	7–9	.....	....	430	7–9

①The solution heat treatment is followed by quenching in water at 150°F to 212°F except for 142-T77 sand castings, which are quenched in still air. A boiling water quench is recommended, since it minimizes quenching stresses and distortion.

②Nominal metal temperature should be maintained with as little variation as possible during the recommended time at temperature. Furnaces capable of maintaining the temperature well within plus or minus 10°F of that desired are readily available.

③The exact time required is influenced by foundry variables and may have to be adjusted, from experience, to secure the typical properties for the alloy and temper.

TABLE 8a

Strengths at Various Temperatures

WROUGHT ALLOYS

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
1060–O	All	TS	222	121	108	100	75	60	44	30	22	17
		YS	120	102	100	100	91	78	62	51	41	31
1060–H12	All	TS	206	117	106	100	83	68	50	25	19	14
		YS	120	106	102	100	84	69	48	21	15	11
1060–H14	All	TS	190	115	105	100	95	79	53	23	16	12
		YS	119	104	102	100	92	76	45	18	13	10
1100–O	All	TS	189	115	104	100	83	67	46	30	21	16
		YS	123	107	103	100	100	91	68	41	33	25
1100–H12	All	TS	170	112	103	100	89	76	60	30	17	14
		YS	115	105	100	100	92	75	50	22	12	9
1100–H14	All	TS	167	111	104	100	89	75	55	23	15	12
		YS	117	103	100	100	89	71	44	13	10	8
1100–H16	All	TS	158	110	103	100	91	78	54	19	14	10
		YS	118	104	101	100	89	74	47	13	9	7
1100–H18	All	TS	144	109	104	100	89	74	25	16	11	9
		YS	120	105	103	100	83	62	18	9	8	6
2011–T3	All	TS	...	...	...	100	85	50	29	12	6	4
		YS	...	...	...	100	73	42	22	8	4	3
2011–T6	All	TS	...	...	...	100	80	48	28	12	5	4
		YS	...	...	...	100	90	52	28	10	5	4
2011–T8	All	TS	...	...	...	100	76	47	27	11	5	4
		YS	...	...	...	100	76	45	24	9	4	3
2014–T4	Rolled Products	TS	128	104	103	100	87	61	26	14	10	7
		YS	132	104	101	100	81	67	29	15	11	8
2014–T4	Forgings	TS	124	103	103	100	85	74	28	17	11	8
		YS	136	102	101	100	89	80	36	24	16	12
2014–T4	Extrusions	TS	130	105	104	100	85	50	22	15	11	8
		YS	136	102	100	100	86	58	24	17	12	8
2014–T6	Rolled Products	TS	120	104	103	100	87	55	24	12	9	6
		YS	116	104	102	100	88	52	22	12	8	6
2014–T6	Forgings	TS	119	104	103	100	88	70	24	14	9	7
		YS	113	103	102	100	91	71	20	13	9	6

See page 79 for footnotes.

TABLE 8a

Strengths at Various Temperatures

WROUGHT ALLOYS—*Continued*

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
2014–T6	Extrusions	TS	124	105	102	100	85	44	19	13	10	7
		YS	125	105	102	100	87	41	17	12	9	5
2017–T4	Rolled Products	TS	128	104	103	100	87	61	26	14	10	7
		YS	132	104	101	100	81	67	29	15	11	8
2018–T61	Forgings	TS	118	104	103	100	92	74	32	17	8	6
		YS	110	103	101	100	94	86	28	14	6	5
2024–T4	All Except Extrusions	TS	127	106	104	100	90	64	39	20	11	7
		YS	133	106	101	100	93	78	45	20	11	8
2024–T4	Extrusions	TS	128	102	100	100	95	61	26	17	10	7
		YS	135	104	100	100	95	68	25	15	11	6
3003–O	All	TS	206	122	107	100	82	68	52	37	25	18
		YS	145	116	105	100	93	83	72	58	41	31
3003–H12	All	TS	179	117	107	100	89	78	63	38	21	15
		YS	125	107	102	100	91	72	49	24	14	11
3003–H14	All	TS	164	109	103	100	92	80	62	34	19	13
		YS	120	104	101	100	89	71	45	21	13	10
3003–H16	All	TS	152	110	104	100	90	79	56	29	16	11
		YS	121	106	102	100	87	72	46	18	11	8
3003–H18	All	TS	143	110	104	100	89	78	51	25	14	10
		YS	122	107	103	100	77	58	32	15	9	7
3004–O	All	TS	164	110	103	100	100	81	55	38	27	18
		YS	133	103	100	100	100	100	94	68	46	28
3004–H32	All	TS	152	109	103	100	99	83	63	43	24	16
		YS	119	102	100	100	100	92	65	31	21	13
3004–H34	All	TS	147	109	102	100	99	82	62	41	22	14
		YS	119	102	100	100	100	87	56	25	17	10
3004–H36	All	TS	143	108	102	100	98	79	57	35	20	13
		YS	120	102	100	100	100	79	47	22	15	9
3004–H38	All	TS	140	107	101	100	97	76	52	29	18	12
		YS	121	102	100	100	100	74	41	20	14	8

See page 79 for footnotes.

Continued on next page

TABLE 8a

Strengths at Various Temperatures

WROUGHT ALLOYS—*Continued*

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
4032–T6	All	TS	119	105	102	100	92	68	24	15	9	6
		YS	103	100	100	100	95	71	19	12	7	4
5050–O	All	TS	171	110	102	100	100	90	60	41	27	18
		YS	125	107	103	100	100	100	88	62	48	35
5050–H32	All	TS	155	108	102	100	100	88	51	35	24	16
		YS	119	101	100	100	100	89	34	24	18	13
5050–H34	All	TS	146	107	102	100	99	86	46	31	21	14
		YS	119	101	100	100	100	88	29	21	16	12
5050–H36	All	TS	143	106	101	100	98	83	42	29	20	13
		YS	120	102	100	100	100	85	27	19	15	11
5050–H38	All	TS	141	106	101	100	98	81	40	28	18	12
		YS	122	103	100	100	100	81	25	18	14	10
5052–O	All	TS	158	106	101	100	99	87	63	45	30	19
		YS	121	100	100	100	100	100	90	60	38	23
5052–H32	All	TS	148	106	101	100	98	82	62	36	24	15
		YS	117	102	100	100	99	87	53	26	17	10
5052–H34	All	TS	144	106	101	100	97	81	62	33	22	14
		YS	118	103	100	100	99	87	46	23	14	9
5052–H36	All	TS	143	105	101	100	97	80	60	31	20	13
		YS	117	102	100	100	98	80	42	21	13	8
5052–H38	All	TS	141	105	101	100	96	79	58	30	20	12
		YS	116	101	100	100	98	77	40	20	12	8
6061–O	All	TS	189	113	105	100	95	84	58	34	21	16
		YS	132	112	106	100	100	100	90	59	31	26
6061–T4	All	TS	144	109	103	100	88	78	53	20	11	8
		YS	131	106	103	100	93	90	75	23	12	10
6061–T6	All	TS	133	110	105	100	91	71	41	15	8	6
		YS	116	105	103	100	92	74	40	12	6	5

See page 79 for footnotes.

TABLE 8a

Strengths at Various Temperatures

WROUGHT ALLOYS—*Concluded*

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
6063–O	All	TS	197	117	106	100	87	74	50	35	25	17
		YS	129	111	105	100	96	90	69	51	38	26
6063–T42	All	TS	153	120	108	100	99	95	42	21	14	10
		YS	126	119	110	100	100	100	48	28	20	14
6063–T5	All	TS	138	108	105	100	87	75	34	17	12	8
		YS	116	105	104	100	94	83	30	17	13	9
6063–T6	All	TS	135	109	103	100	89	60	26	13	9	6
		YS	116	106	102	100	92	64	20	12	8	6
6151–T6	All	TS	125	107	104	100	89	57	25	14	11	9
		YS	115	106	104	100	91	57	22	13	10	8
7075–T6	All	TS	123	105	103	100	78	30	18	13	10	7
		YS	124	105	102	100	80	28	16	12	8	6

The values of tensile strength and yield strength obtained through the application of percentages given in this table are those which apply while the metal is at the temperature indicated. In some cases lower strengths are encountered after short periods of heating than after long periods; in such cases the lower values are listed. In most cases the application of heat will also result in lower properties at room temperature as indicated for several alloys and tempers in Table 8c.

Under some conditions of temperature and time the application of heat will adversely affect the resistance of some of the alloys to corrosion. For specific information concerning the suitability of the various alloys for use at elevated temperatures, the nearest sales office of Aluminum Company of America should be consulted.

TABLE 8b

Strengths at Various Temperatures

CAST ALLOYS

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
122–T551	Permanent-Mold Castings	TS	...	...	...	100	91	81	67	49	24	14
		YS	...	...	...	100	93	78	57	34	15	7
122–T61	Sand Castings	TS	...	...	...	100	94	87	59	41	20	12
		YS	...	...	...	100	96	88	44	28	13	6
142–T571	Sand Castings	TS	...	...	...	100	100	97	81	41	25	14
		YS	...	...	...	100	100	100	70	24	13	8
142–T571	Permanent-Mold Castings	TS	...	...	...	100	99	92	65	33	20	11
		YS	...	...	...	100	99	96	62	21	12	7
142–T77	Sand Castings	TS	124	108	103	100	99	93	71	44	27	15
		YS	121	106	102	100	100	93	68	31	17	11
195–T4	Sand Castings	TS	...	...	...	100	95	86	46	28	12	8
		YS	...	...	...	100	91	91	56	36	18	11
195–T6	Sand Castings	TS	...	...	...	100	97	78	42	25	11	7
		YS	...	...	...	100	95	80	36	24	12	7
214–F	Sand Castings	TS	...	...	...	100	94	88	72	52	36	20
		YS	...	...	...	100	100	100	100	67	33	18
355–T51	Sand Castings	TS	118	105	101	100	99	89	46	27	16	11
		YS	122	109	104	100	94	87	41	22	13	9
355–T6	Sand Castings	TS	...	...	...	100	100	94	37	21	13	9
		YS	...	...	...	100	100	100	38	20	12	8
355–T6	Permanent-Mold Castings	TS	...	...	...	100	91	76	30	17	10	7
		YS	...	...	...	100	100	100	35	19	11	7
355–T7	Sand Castings	TS	116	106	103	100	97	85	34	20	12	8
		YS	107	100	100	100	93	81	26	14	8	6
355–T71	Permanent-Mold Castings	TS	...	...	...	100	90	75	36	21	12	8
		YS	...	...	...	100	91	71	31	16	10	6

See page 81 for footnotes.

TABLE **8b**

Strengths at Various Temperatures

CAST ALLOYS—*Concluded*

(After 10,000 Hours at Testing Temperature)

Tensile and Yield Strengths Expressed in Per Cent of Room Temperature Values

Alloy and Temper	Product	Property	−320° F	−110° F	−20° F	75° F	212° F	300° F	400° F	500° F	600° F	700° F
356–T51	Sand Castings	TS	126	108	104	100	92	83	48	30	16	8
		YS	108	102	100	100	98	84	48	25	12	8
356–T6	Sand Castings	TS	...	...	...	100	89	76	37	23	12	6
		YS	...	...	...	100	97	89	40	21	10	6
356–T6	Permanent-Mold Castings	TS	...	...	...	100	73	51	26	16	10	5
		YS	...	...	...	100	90	69	31	17	9	6
356–T7	Sand Castings	TS	119	104	102	100	86	74	35	22	12	6
		YS	115	104	102	100	94	79	32	17	8	5
356–T7	Permanent-Mold Castings	TS	133	107	103	100	84	62	31	19	12	6
		YS	119	107	103	100	92	78	35	19	10	6

The values of tensile strength and yield strength obtained through the application of percentages given in this table are those which apply while the metal is at the temperature indicated. In some cases lower strengths are encountered after short periods of heating than after long periods; in such cases the lower values are listed. In most cases the application of heat will also result in lower properties at room temperature.

Under some conditions of temperature and time the application of heat will adversely affect the resistance of some of the alloys to corrosion. For specific information concerning the suitability of the various alloys for use at elevated temperatures, the nearest sales office of Aluminum Company of America should be consulted.

TABLE 8c

Strengths at Room Temperature After Heating

WROUGHT ALLOYS

(10,000 Hours at Various Temperatures)

Tensile and Yield Strengths in Per Cent of Strength for Unheated Specimens

Alloy and Temper	Product	Property	75°F	212°F	300°F	400°F	500°F	600°F	700°F
6061–T6	All	TS	100	101	82	60	38	34	..
		YS	100	105	85	50	17	13	..
6063–T42	All	TS	100	104	107	73	53	49	48
		YS	100	109	117	62	38	32	22
6063–T5	All	TS	100	100	95	60	43	40	39
		YS	100	100	90	38	24	20	17
6063–T6	All	TS	100	100	81	46	33	31	30
		YS	100	100	75	26	16	14	12
7075–T6	All	TS	100	94	48	36	..	..	..
		YS	100	88	32	20	..	..	..

For some alloys and tempers lower strengths are encountered after short periods of heating at certain temperatures than after long periods; in such cases the lower values are listed.

TABLE 9

Fatigue Strengths

Approximate Average, as Determined by Tests in R. R. Moore Rotating-Beam Fatigue Machines

All values in kips per sq in.

See pages 13 and 18 for comments on this table.

Alloy and Temper	Approximate Completely Reversed Flexural Stresses That Material Will Withstand for Various Numbers of Cycles				
	100,000 Cycles	1,000,000 Cycles	10,000,000 Cycles	100,000,000 Cycles	500,000,000 Cycles
1060–H12	8	6.5	5.5	4.5	4
1100–O	.....	6.5	5.5	5	5
1100–H16	14	11.5	10	9	8
2011–T3	35	26.5	22.5	19.5	18
2014–T4 and 2017–T4	42	34	27	22	20
2014–T6	39	30	24	19	18
2018–T61	42	29	23	19.5	17
2024–T4	43	31	24	21	20
3003–O	10.5	9	8	7.5	7
3003–H14	17	12	10	9	9
3003–H18	19	14	11.5	10.5	10
3004–O	19.5	16.5	15.5	14.5	14
3004–H34	25	20	17.5	16.5	16
3004–H38	28.5	23	20.5	19	18
4032–T6	37	30	23.5	18	16
5050–O	17.5	14.5	13.5	13	12.5
5050–H34	22.5	19	17.5	16.5	16
5050–H38	25	20.5	19	18.5	18
5052–O	23.5	19.5	17.5	16.5	16
5052–H34	26	20.5	19	18	18
5052–H38	29.5	24	22.5	21	20
6061–O	16	13.5	11	9.5	9
6061–T4	27.5	22.5	17.5	15	13.5
6061–T6	31	23	17	14.5	13.5
6063–T42	19.5	16	13.5	11	9.5
6063–T5	20.5	15.5	12	10.5	9.5
6063–T6	23.5	16.5	13.5	11	9.5
6151–T6	30	22	17	13	12
7075–T6	40	29	24	22	22
Sand-cast Test Bars—All Alloys	20±5	14±3	11±2.5	9±2	9±2
Die-cast Test Bars of Alloys 218, 360 and 380	30	25	23	21	20

TABLE 10

Fatigue Strengths

Approximate Average, as Determined by Tests in ARL Direct-Stress Fatigue Testing Machines

All values of stress in kips per sq in.;
plus (+) means tension, minus (−) means compression.
See pages 13 and 18 for comments on this table.

Alloy and Temper	Minimum Stress in Each Cycle	Approximate Maximum Stress for Number of Cycles Indicated					
		10,000 Cycles	100,000 Cycles	1,000,000 Cycles	10,000,000 Cycles	100,000,000 Cycles	500,000,000 Cycles
2014–T6	−40	+49	+27	+11	0	....	....
	−35	+52	+31	+16	+ 5	....	....
	−30	+55	+35	+21	+10	+ 3	0
	−25	+57	+39	+25	+15	+ 8	+ 5
	−20	+59	+42	+29	+20	+13	+10
	−15	+61	+45	+33	+24	+18	+15
	−10	+63	+48	+36	+28	+23	+20
	− 5	+65	+51	+39	+32	+28	+25
	0	+66	+54	+42	+36	+32	+30
	+ 5	+67	+57	+45	+40	+36	+35
	+10	....	+59	+48	+44	+40	+39
	+15	....	+61	+51	+48	+44	+43
	+20	....	+63	+54	+51	+48	+47
	+25	....	+65	+57	+54	+52	+51
	+30	....	+67	+60	+57	+56	+55
	+35	....	+68	+62	+60	+59	+58
2024–T4	−40	....	+31	+15	+ 2	....	....
	−35	....	+35	+20	+ 7	+ 1	....
	−30	....	+38	+24	+12	+ 6	+ 4
	−25	....	+41	+28	+17	+11	+ 9
	−20	....	+44	+32	+21	+16	+14
	−15	....	+47	+35	+25	+20	+19
	−10	....	+49	+38	+29	+25	+24
	− 5	....	+52	+41	+33	+30	+29
	0	....	+54	+44	+37	+34	+33
	+ 5	....	+56	+46	+40	+38	+37
	+10	....	+58	+49	+44	+42	+41
	+15	....	+60	+51	+47	+46	+45
	+20	....	+62	+53	+50	+49	+48
5052–H36	−25	....	+19	+ 9	+ 5	+ 4	+ 4
	−20	....	+22	+14	+11	+10	+10
	−15	....	+26	+19	+16	+15	+15
	−10	....	+29	+24	+21	+20	+20
	− 5	....	+32	+28	+26	+25	+25
	0	....	+34	+32	+31	+30	+30
	+ 5	....	+36	+35	+34	+33	+33

TABLE 10

Fatigue Strengths—*Concluded*

Approximate Average, as Determined by Tests in ARL Direct-Stress Fatigue Testing Machines

All values of stress in kips per sq in.;
plus (+) means tension, minus (−) means compression.
See pages 13 and 18 for comments on this table.

Alloy and Temper	Minimum Stress in Each Cycle	Approximate Maximum Stress for Number of Cycles Indicated					
		10,000 Cycles	100,000 Cycles	1,000,000 Cycles	10,000,000 Cycles	100,000,000 Cycles	500,000,000 Cycles
6061-T6	−35	+32	+19	+ 5	....	....	....
	−30	+34	+22	+10	+ 3	....	....
	−25	+37	+25	+14	+ 8	+ 3	+ 2
	−20	+39	+28	+18	+12	+ 7	+ 6
	−15	+40	+31	+22	+15	+11	+10
	−10	+42	+33	+25	+19	+15	+14
	− 5	+43	+36	+28	+23	+19	+18
	0	+44	+38	+31	+26	+23	+22
	+ 5	....	+40	+33	+29	+27	+26
	+10	....	+41	+36	+33	+31	+30
	+15	....	+42	+38	+36	+35	+34
	+20	....	+43	+41	+39	+38	+37
7075-T6	−55	+52	+28	+10	0	....	....
	−50	+55	+31	+13	+ 3	0	....
	−45	+58	+34	+17	+ 7	+ 4	+ 1
	−40	+60	+37	+20	+11	+ 8	+ 5
	−35	+62	+39	+23	+14	+11	+ 9
	−30	+64	+42	+27	+18	+15	+13
	−25	+66	+45	+30	+21	+18	+16
	−20	+68	+47	+33	+25	+22	+20
	−15	+70	+50	+36	+28	+26	+24
	−10	+72	+52	+39	+31	+29	+27
	− 5	+74	+55	+42	+35	+33	+31
	0	+75	+57	+45	+38	+36	+35
	+ 5	+76	+60	+48	+42	+40	+39
	+10	....	+62	+50	+45	+43	+42
	+15	....	+64	+53	+49	+47	+46
	+20	....	+67	+56	+52	+50	+49
Heat-treated Sand-cast Alloys	−10	....	....	9±2	4±1.5	2±1.5	1±1
	− 5	....	....	12±2	7±1.5	6±1	5±1
	0	....	....	15±2	11±1	10±1	9±1
	+ 5	....	....	18±2	14±1.5	13±1.5	13±1
	+10	....	....	20±2.5	18±1.5	17±1.5	16±1.5

TABLE 11

Approximate Radii① for 90° Cold Bends

SHEET AND PLATE

Alloy and Temper	Radii for Various Thicknesses Expressed in Terms of Thickness "t"							
	1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
1100-O	0	0	0	0	0	0	0	1t–2t
1100-H12	0	0	0	0	0–1t	0–1t	0–1t	1t–3t
1100-H14	0	0	0	0	0–1t	0–1t	0–1t	2t–3t
1100-H16	0	0	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2 1/2t–3 1/2t	3t–4t
1100-H18	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2t–4t	3t–5t	3t–6t
Alclad 2014-O	0	0	0	0	0–1t	0–1t	1 1/2t–3t	3t–5t
Alclad 2014-T3	1t–2t	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t	5 1/2t–8t
Alclad 2014-T4	1t–2t	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t	5 1/2t–8t
Alclad 2014-T6	2t–4t	3t–5t	3t–5t	4t–6t	5t–7t	6t–10t	7t–10t	8t–11t
2024-O②	0	0	0	0	0–1t	0–1t	1 1/2t–3t	3t–5t
2024-T3②③	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t	6t 8t	6t–9t
2024-T36②	2t–4t	3t–5t	4t–6t	5t–7t	5t–7t	6t–10t	7t–10t	8t–11t
2024-T4②	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t	6t–8t	6t–9t
2024-T81	3 1/2t–5t	4 1/2t–6t	5t–7t	6 1/2t–8t	7t–9t	8t–10t	9t–11t	9t–12t
2024-T86	4t–5 1/2t	5t–7t	6t–8t	7t–10t	8t–11t	9t–11t	10t–13t	10t–13t
3003-O	0	0	0	0	0	0	0	1t–2t
3003-H12	0	0	0	0	0–1t	0–1t	0–1t	1t–3t
3003-H14	0	0	0	0–1t	0–1t	1/2t–1 1/2t	1t–2 1/2t	1 1/2t–3t
3003-H16	0–1t	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2 1/2t–4t	3t–5t
3003-H18	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–7t	5t–8t
3004-O	0	0	0	0	0–1t	0–1t	1/2t–1 1/2t	1t–2t
3004-H32	0	0	0	0–1t	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–2 1/2t
3004-H34	0	0	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–3t	2 1/2t–3 1/2t
3004-H36	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2t–4t	2 1/2t–5t	3t–5 1/2t
3004-H38	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–7t	5t–8t

Alloy and Temper	Radii for Various Thicknesses Expressed in Terms of Thickness "t"							
	1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
5005-O	0	0	0	0	0	0	0	1t-2t
5005-H12	0	0	0	0	0-1t	0-1t	0-1t	1t-3t
5005-H14	0	0	0	0-1t	0 1t	1/2t 1 1/2t	1t 2 1/2t	1 1/2t 3t
5005-H16	0-1t	0 1t	1/2t-1 1/2t	1t 2t	1 1/2t 3t	2t-4t	2 1/2t 4t	3t-5t
5005-H18	1/2t-1 1/2t	1t-2t	1 1/2t 3t	2t 4t	3t-5t	4t 6t	4t 7t	5t 8t
5005-H32	0	0	0	0	0-1t	0-1t	0-1t	1t-3t
5005-H34	0	0	0	0-1t	0-1t	1/2t 1 1/2t	1t 2 1/2t	1 1/2t 3t
5005-H36	0-1t	0-1t	1/2t-1 1/2t	1t 2t	1 1/2t-3t	2t 4t	2 1/2-4t	3t 5t
5005-H38	1/2t-1 1/2t	1t 2t	1 1/2t-3t	2t 4t	3t 5t	4t-6t	4t-7t	5t 8t
5050-O	0	0	0	0	0	0	.....	.....
5050-H32	0	0	0	0	0 1t	1/2t 1 1/2t	2t-3 1/2t	2 1/2t-4t
5050-H34	0	0	0	0-1t	1/2t 1 1/2t	1t 2t	2t-4t	3t-4t
5050-H36	0-1t	0-1t	1/2t-1 1/2t	1t 2t	1 1/2t 3t	2t 4t	2 1/2 4t	3t-5t
5050-H38	1/2t-1 1/2t	1t 2t	1 1/2t-3t	2t 4t	3t 5t	4t 6t	4t 7t	5t 8t
5052-O	0	0	0	0	0-1t	0-1t	1/2t-1 1/2t	1t-2t
5052-H32	0	0	0	0 1t	0-1t	1/2t 1 1/2t	1t 2t	1 1/2t 2 1/2t
5052-H34	0	0	0 1t	1/2t-1 1/2t	1t 2t	1 1/2t 3t	2t-3t	2 1/2t 3 1/2t
5052-H36	0 1t	1/2t-1 1/2t	1t-2t	1 1/2t-3t	2t 4t	2t 4t	2 1/2t 5t	3t 5 1/2t
5052-H38	1/2t-1 1/2t	1t-2t	1 1/2t-3t	2t-4t	3t-5t	4t 6t	4t 7t	5t 8t
5083-O	.....	.....	0-1/2t	0-1t	0-1t	1/2t-1 1/2t	1 1/2t-2t	1 1/2t-2 1/2t
5086-O	0	0	0	0-1t	0-1t	1/2t-1t	1/2t-1t	1/2t-1 1/2t
5086-H112	0-1/2t	0-1/2t	1/2t-1t	1/2t-1 1/2t	1t-1 1/2t	1t-2t	1t-2t	1 1/2t-2 1/2t
5086-H32	0-1/2t	0-1t	1/2t-1 1/2t	1t-2t	1 1/2t-2t	1 1/2t 2 1/2t	2t-2 1/2t	2 1/2t-3t
5086-H34	0-1t	1/2t-1 1/2t	1t-2t	1 1/2t-2 1/2t	2t-3t	2t 3t	2 1/2t-3 1/2t	3t-4t
5086-H36	.....	.....	.....	2t-3 1/2t	2 1/2t-4t	3t-4 1/2t	3t-5t	3 1/2t-5 1/2t

See page 88 for footnotes.

Continued on next page

TABLE 11

Approximate Radii① for 90° Cold Bends—Concluded

SHEET AND PLATE

Alloy and Temper	Radii for Various Thicknesses Expressed in Terms of Thickness "t"							
	1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
5154-O	0	0	0	0–1t	0–1t	1/2t–1 1/2t	1/2t–1 1/2t	1t–2t
5154-H112	.....	.....	.....	.....	.....	1 1/2t–3t	2 1/2t–4t	3t–5t
5154-H32	0	0	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2 1/2t–5t
5154-H34	0–1t	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2 1/2t–4 1/2t	3t–5t
5154-H36	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2t 4t	2 1/2t–5t	3t–6t
5154-H38	1t–2t	1 1/2t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–8t	5t–8t
5456-O	.....	.....	.....	0–1t	1/2t–1t	1/2t–1t	1/2t 1 1/2t	1/2t–2t
5456-H321	.....	.....	.....	2t–3t	3t–4t	2t–3t	3t–4t	3t–4t
6061-O	0	0	0	0	0–1t	0–1t	1/2t 2t	1t–2 1/2t
6061-T4	0–1t	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	2 1/2t 4t	3t–5t
6061-T6	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2t–4t	3t–4t	3 1/2t 5 1/2t	4t–6t
7075-O	0	0	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2 1/2t–4t	3t–5t
7075-T6②	2t–4t	3t–5t	4t–6t	5t–7t	5t 7t	6t–10t	7t–11t	7t–12t
7178-O	0	0	0–1t	1/2t–1 1/2t	1t–2t	1 1/2t–3t	2 1/2t–4t	3t–5t
7178-T6	2t–4t	3t–5t	4t–6t	5t–7t	5t–7t	6t–10t	7t–11t	7t–12t

①Minimum permissible radius over which sheet or plate may be bent varies with nature of forming operation, type of forming equipment, and design and condition of tools. Minimum working radius for a given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

②Alclad sheet can be bent over slightly smaller radii than the corresponding tempers of the uncoated alloy.

③Immediately after quenching, this alloy can be formed over appreciably smaller radii.

TABLE 12

Approximate Thermal Expansion

WROUGHT ALLOYS

Temperature Range from −50°F to +150°F

Length in Feet	Change in Length in inches									
	Temperature Change in Degrees Fahrenheit									
	10	20	30	40	50	60	70	80	90	100
10	0.015	0.030	0.045	0.060	0.075	0.090	0.105	0.120	0.135	0.150
20	0.030	0.060	0.090	0.120	0.150	0.180	0.210	0.240	0.270	0.300
30	0.045	0.090	0.135	0.180	0.225	0.270	0.315	0.360	0.405	0.450
40	0.060	0.120	0.180	0.240	0.300	0.360	0.420	0.480	0.540	0.600
50	0.075	0.150	0.225	0.300	0.375	0.450	0.525	0.600	0.675	0.750
60	0.090	0.180	0.270	0.360	0.450	0.540	0.630	0.720	0.810	0.900
70	0.105	0.210	0.315	0.420	0.525	0.630	0.735	0.840	0.945	1.050
80	0.120	0.240	0.360	0.480	0.600	0.720	0.840	0.960	1.080	1.200
90	0.135	0.270	0.405	0.540	0.675	0.810	0.945	1.080	1.215	1.350
100	0.150	0.300	0.450	0.600	0.750	0.900	1.050	1.200	1.350	1.500

Coefficient of thermal expansion per degree Fahrenheit taken as 0.0000125 for wrought aluminum alloys, which is approximately 1.9 times value for medium structural steel.

TABLE 13

Data on Alclad Products

Core Alloy	Product	Nominal Over-all Thickness, in.	Alloy of Cladding	Nominal Thickness of Cladding on One Surface in Per Cent of Total Thickness	Factor, H, in Formulas (17) and (18) for Equivalent Slenderness Ratio of Alclad Plates (see pages 146 and 147)
2014	Sheet clad both sides	0.024 and under	6003	10	0.95
2014	Sheet clad both sides	0.025 to 0.039	6003	7½	0.96
2014	Sheet clad both sides	0.040 to 0.099	6003	5	0.98
2014	Sheet and plate clad both sides	0.100 and over	6003	2½	0.99
2024	Sheet clad both sides	0.062 and under	1230	5	0.96
2024	Sheet and plate clad both sides	0.063 and over	1230	2½	0.98
3003	Sheet clad one side only	0.064 and under	7072	15	0.98
3003	Sheet clad one side only	0.065 and over	7072	7½	0.99
3003	Sheet and plate clad both sides	All	7072	10	0.98
3003	Tubes clad inside, outside, or both sides	All	7072	10	0.99
3004	Sheet and plate clad both sides	All	7072	5	0.98
6061	Sheet and plate clad both sides	All	7072	5	0.96
7075	Sheet clad both sides	0.062 and under	7072	4	0.96
7075	Sheet clad both sides	0.063 to 0.187	7072	2½	0.98
7075	Sheet and plate clad both sides	0.188 and over	7072	1½	0.99
7178	Sheet and plate clad both sides	All	7072	4	0.96

DESIGN OF
ALUMINUM ALLOY STRENGTH MEMBERS

Design of
Aluminum Alloy Strength Members

DESIGN RULES

Rules for calculating the strength of various components of aluminum alloy assemblies are given in this portion of the handbook. The problem of designing such assemblies on the basis of the strength of the individual parts or members is essentially the same as for other engineering materials.

In designing parts to carry load, the engineer strives to achieve not only adequate strength but also economy of material. The latter is particularly important in aluminum alloy strength members because this light metal is often chosen to eliminate needless dead weight.

Factor of Safety

A margin of safety may be obtained either by designing for loads higher than expected or by scaling down the stresses representing the strength of a member to allowable or design stress values. The ratio of the ultimate strength stress to the allowable design stress is frequently referred to as the factor of safety.

This handbook is concerned with the strength of aluminum alloy members, and no attempt is made to specify allowable design stresses or factors of safety. An appropriate factor of safety, however, should always be applied. The magnitude of the factors of safety chosen will be influenced by such considerations as:

(a) The precision with which the assumed loadings (including impact and repeated as well as static loads) represent the actual service loading, both present and future.

(b) The precision with which the strength of the structure can be calculated for the various types of loading.

(c) The importance of the structure being designed and the consequences of failure.

(d) Precedent established by generally accepted specifications applying to the type of structure being designed.

Examples of the latter, which may be of assistance to the designer of civil engineering type structures, are the specifications for 2014-T6 and 6061-T6 aluminum alloy structures written by the American Society of Civil Engineers Committee on Design in Lightweight

Structural Alloys.[1] These specifications are intended to provide a factor of safety of 2.5 on ultimate strength. This factor is applied, for instance, to the buckling strength of columns and beams, since buckling of these members will generally precipitate complete collapse. Where buckling will not cause immediate collapse, as in buckling of a girder web, the ASCE Committee has used lower factors of safety (1.5 or 2.0). In the field of pressure vessel design, for aluminum alloys as well as other metals, the American Society of Mechanical Engineers Boiler Construction Code[2] recommends a factor of safety of 4 against bursting or 1.5 against yielding, whichever gives the more conservative design.

YIELDING AND FRACTURE

The first two modes of failure discussed are those described as yielding and fracture, in which no problem of buckling is involved. Consideration is given to tension, compression, bearing, bending, shear, torsion, combined stress, creep and fatigue. All problems involving buckling are covered separately in the section of this chapter entitled "Buckling," pages 110 to 163.

Tension

For a member loaded in static axial tension, two important strength considerations are of interest to the designer: first, the load at which the member begins to yield or take appreciable permanent set, and second, the load at which fracture occurs. Appreciable yielding may be expected when the average stress on the minimum net section reaches the tensile yield strength of the material. Fracture may be expected when the stress on the minimum net section is equal to the tensile strength of the material.

In establishing the minimum net section, the following comments may be helpful. The net section of a riveted tension member is the sum of the net sections of its component parts. The net section of a part is the product of the thickness of the part multiplied by its least net width. The net width for a single line of holes extending across the part may be obtained by deducting from the gross width

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[1] "Specifications for Structures of Aluminum Alloy 2014-T6" and "Specifications for Structures of Aluminum Alloy 6061-T6," Progress Reports of the Committee of the Structural Division on Design in Lightweight Structural Alloys, Journal of the Structural Division, *Proceedings*, ASCE, Vol. 82, 1956 (These specifications are reproduced in full at the back of this handbook.)

[2] "Rules for Construction of Unfired Pressure Vessels," Report of Subcommittee of Boiler Code Committee on Unfired Pressure Vessels, *ASME Boiler and Pressure Vessel Code*, Section VIII, 1952, p. 162.

the sum of the diameters of all the holes in the line. Where the holes are staggered in two or more lines across the members, the net width for a broken line of holes may be obtained by deducting from the gross width the sum of the diameters of all holes in the broken line and adding $\frac{s^2}{4g}$ for each gage space in the chain, where:

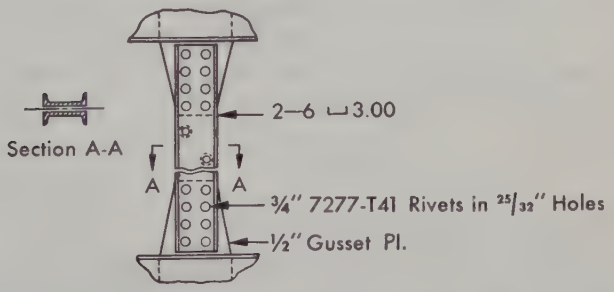
s = the spacing parallel to direction of load (pitch) of any two successive holes in the chain, in inches, and

g = the spacing perpendicular to direction of load (gage) of the same holes, in inches.

The minimum or controlling net section of a part is obtained from that chain of holes which gives the least net width.

It is a well known fact that holes and other discontinuities produce localized concentrations of stress. For the wrought aluminum alloys, however, such stress concentrations can ordinarily be ignored in calculating the static strength of tension members. All the wrought materials considered herein have sufficient ductility to permit adequate alleviation of stress concentrations by local yielding before static fracture occurs. Stress concentration is important, however, when a load is applied repeatedly for a large number of cycles so that fatigue failure is a possibility (see pages 107 to 110).

Example 1. Check the 6061-T6 tension hanger shown in the sketch to insure a factor of safety of at least 1.5 against yielding and at least 2.2 against fracture when maximum service loading is 70 kips.



The minimum tensile properties from Table 4c, page 52, (standard structural shapes) are: yield strength = 35 kips per sq in., ultimate strength = 38 kips per sq in.

Minimum net section = $5.10 - 4 \times \frac{25}{32} \times .225 = 4.40$ in.^{2}

Yield load = $4.40 \times 35 = 154$ kips

Fracture load = $4.40 \times 38 = 167$ kips

Factor of safety on yield = $154/70 = 2.20$

Factor of safety on fracture = $167/70 = 2.39$

Since both safety factors exceed the desired values, the member may be considered safe from the standpoint of tensile yielding and fracture.

Compression

Generally the strength of compression members is controlled by buckling, which is treated in the section of this chapter entitled "Buckling," pages 110 to 163. Occasionally, however, the engineer will encounter short, compact compression members in which there is no possibility of buckling failure. In such cases, he will be concerned only with the problem of avoiding appreciable yielding by keeping the average stress on the cross section below the compressive yield strength of the material.

All the wrought aluminum alloys considered in this handbook are sufficiently ductile so that fracture need not be feared in short, compact compression members. If the loading is increased beyond the compressive yield strength, the material merely flows laterally, providing increase in area to support the increase in load.

In calculating the effective cross-sectional area of compression members, allowance should be made for any open holes. Holes well filled with rivets or tightly fitted bolts may be ignored in calculating the effective cross-sectional area.

Bending

The design of members that must resist bending moments, and that are sufficiently compact so no buckling problem exists, is usually a problem simply of providing a suitable margin of safety against yielding or fracture.

As in the case of parts loaded in axial tension, yielding may be avoided by keeping the extreme fiber stress on the net section below the yield strength. The extreme fiber stress in the beam is calculated by the well-known flexure formula,

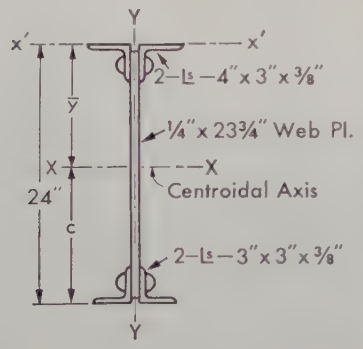
$$f = \frac{Mc}{I}$$

where f = extreme fiber stress, kips per sq in.,
M = applied bending moment, in.-kips,
c = the distance from the neutral axis to the extreme fiber, in.,
I = moment of inertia of the cross section about its neutral axis, in.^{4}

The quantity $\frac{I}{c}$ is known as the section modulus, S. Formulas for moment of inertia, I, and section modulus, S, of various cross sections are given in Table 60, pages 271 to 273. Values of I and S for structural shapes are given in Tables 40 to 53, pages 212 to 235. Formulas for bending moments for various loadings on beams are given on pages 201 to 205. For members such as I-beams, channels

and plate girders, a suggested procedure for calculating the extreme fiber stress on the net section of the tension flange is to calculate first a stress on the gross section, using the flexure formula, page 96, and then multiply this by the ratio of the gross area of the tension flange to the net area. In determining this ratio the tension flange is considered to consist of the flange proper plus that part of the web included in the outermost one-sixth of the over-all height of the beam or girder.

For members whose resistance to bending is provided mostly by the material in the flanges, such as I-beams, channels and plate girders, the flexure formula can be applied for stresses in either the elastic or plastic stress ranges. Therefore, the stress on the net section of the tension flange, calculated as outlined above, may be compared to the tensile yield strength to determine the factor of safety against yielding and to the tensile ultimate strength to find the factor of safety against fracture.



Example 2. Check net section stress in the tension (bottom) flange of the plate girder shown in the sketch for a bending moment of 1,500 in.-kips. Determine the factor of safety against yielding and fracture, assuming all parts are of 6061-T6 alloy and the rivet holes are $^{21}/_{32}$ in. in diameter.

Section Elements

Section	Weight Lb/Ft	Area Sq In.	For Axis X'			
			y In.	Ay In.³	Ay² In.⁴	I_o In.⁴
2 angles 4"×3"×⅜"	5.85	4.98	0.77	3.8	3	4
1 plate ¼"×23¾"	6.98	5.94	12.00	71.3	855	279
2 angles 3"×3"×⅜"	4.95	4.20	23.13	97.1	2247	3
	17.78	15.12		172.2	3105	286

$$\bar{y}=\frac{\Sigma Ay}{A}=\frac{172.2}{15.12}=11.4 \text{ in.}$$

$$c=24-11.4=12.6 \text{ in.}$$

$$I_x=\Sigma I_o+\Sigma Ay^2-\bar{y}\Sigma Ay=286+3105-11.4\times 172.2=1430 \text{ in.}^4$$

$$S_{(\text{tension flange})}=\frac{1430}{12.6}=114 \text{ in.}^3$$

Gross area of tension flange:

Area of 2 angles $3'' \times 3'' \times \frac{3}{8}'' = 4.20$ in.^{2}

Area of plate in outermost one-sixth of depth of girder $= \underline{0.97 \text{ in.}^2}$

5.17 in.^2

Net area of tension flange:

Projected area of $\frac{21}{32}''$ rivet hole $= \frac{21}{32} \times (\frac{3}{8} + \frac{3}{8} + \frac{1}{4}) = 0.66$ in.^{2}

Net area $= 5.17 - 0.66 = 4.51$ in.^{2}

The tension flange stress based on the gross area is

$$f = \frac{M}{S} = \frac{1500}{114} = 13.2 \text{ kips per sq in.}$$

The average stress on the net area of the tension flange is

$$13.2 \frac{\text{gross area}}{\text{net area}} = 13.2 \times \frac{5.17}{4.51} = 15.1 \text{ kips per sq in.}$$

Minimum mechanical properties for standard angles (Table 4c, page 52):

Ultimate tensile strength $= 38$ kips per sq in.

Tensile yield strength $= 35$ kips per sq in.

The factor of safety on yielding is $\frac{35}{15.1} = 2.32$ and on ultimate strength is $\frac{38}{15.1} = 2.52$

In the case of members that have considerable cross-sectional area near the neutral axis, such as solid rounds and rectangles, the flexure formula does not apply for stresses above the yield strength because yielding produces a redistribution of stress in the cross section. As a result, the ultimate bending strength of these members is considerably greater than the strength that would be computed by substituting the ultimate tensile strength in the flexure formula. Tests on aluminum alloy beams have shown that an approximate value of the maximum bending moment which these members will carry may be calculated by assuming that the stresses, both tension and compression, reach a value equal to the ultimate tensile strength at every point on the cross section. Formulas for calculating the ultimate bending moment for a few typical beams, based on this method, are listed in Table 14, page 100. For round tubes the bending strength may be calculated from formulas (24) and (25), pages 156 and 158.

Example 3. Find the factor of safety against yielding and ultimate strength for a 1½-in. square 6061-T6 alloy rolled bar carrying a bending moment of 13 in.-kips.

From Table 4d, page 54, the minimum tensile properties of this material are: ultimate strength $= 42$ kips per sq in.; yield strength $= 35$ kips per sq in.

The section modulus of the bar is (see Table 60, page 271)

$$S=\frac{d^3}{6}=\frac{(1.5)^3}{6}=0.562 \text{ in.}^3$$

The extreme fiber bending stress at a bending moment of 13 in.-kips is

$$f=\frac{M}{S}=\frac{13}{0.562}=23.1 \text{ kips per sq in.}$$

Thus the factor of safety on yielding is $\frac{35}{23.1}=1.52$

Since the flexure formula, page 96, does not apply for this type of section at stresses above the yield strength, it cannot be used to determine factor of safety on ultimate strength. To calculate the ultimate bending strength, use the formula (Table 14, page 100):

$$M_u=1.5\ F_{TU}\ S=1.5\times 42\times 0.562=35.4 \text{ in.-kips.}$$

The factor of safety on ultimate strength is $\frac{35.4}{13}=2.72$

Another restriction on the flexure formula, page 96, is that it applies only to cases of symmetrical bending, that is, where the plane of loading is parallel to a principal axis of the cross section. Cases of unsymmetrical bending, in which the plane of the loads is inclined to the principal axes of the cross section, may be handled by dividing the load into components parallel and perpendicular to the principal axes, and adding the stresses caused by these two sets of loads.

Bearing

When a load is transmitted from one part to another through a rivet, bolt or pin, the fastener will exert compressive forces against the edges of the hole, tending to crush the metal ahead of the fastener or tear the hole out if it is near the edge of the piece. Ordinarily, no problem of buckling is involved, and the designer need only keep the average bearing stresses safely below the bearing yield strength or the bearing ultimate strength in order to prevent yielding or fracturing. It is well to remember that the values of bearing yield and bearing ultimate strengths listed in Table 4, pages 42 to 66, of this handbook are established for one value of edge distance only and should be modified for smaller edge distances as described in more detail in the section of the handbook dealing with the design of connections, page 169.

Shear

Yield and ultimate strengths of aluminum alloy members in shear may be calculated from the values of shear yield and shear ultimate strengths for the various alloys listed in Table 4, pages 42 to 66.

In calculating the effective shear area of a part, allowance should be made for all open holes. Holes well filled with rivets or bolts need

TABLE 14

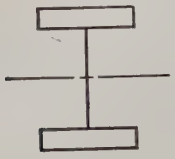
Ultimate Strength of Beams

(When Strength is Not Controlled by Buckling)

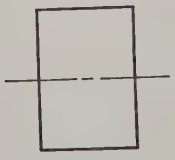
M_u = approximate ultimate bending moment, in.-kips

F_{TU} = ultimate tensile strength, kips per sq in.

S = section modulus $\left(\frac{I}{c}\right)$ in plane of bending, in.^{3}



$M_u = F_{TU}S$



$M_u = 1.5\ F_{TU}S$

$M_u = 1.7\ F_{TU}S$

$M_u = 2.0\ F_{TU}S$

not be considered in calculating the effective shear area as far as yielding is concerned but should be treated as open holes as far as shear ultimate is concerned.

For members with webs, such as I's, channels or plate girders, an approximate value of the shear stress caused by transverse loads may be computed by assuming that the shear is carried entirely by the web or webs and is uniformly distributed over the web area.

Torsion

A member that transmits a torque is subjected to shearing stresses and its yield and ultimate strengths are related to the shear yield and ultimate strengths of the material. Buckling may also be involved if some element of the member is thin enough to permit local wrinkling. The subject of buckling under shear stresses is covered in the section of this chapter entitled "Buckling," pages 110 to 163.

In Table 15a, page 102, formulas are given for computing the maximum shear stress caused by torsion loads for some common cross sections. These formulas are based on elastic behavior. For design purposes, they may be used to calculate the torque that will cause stresses equal to the shear yield strength on a given section. The formulas no longer apply after appreciable yielding has occurred, however, because yielding produces a redistribution of stress. An approximate value of ultimate torque for a member may be determined by assuming that the shear strength of the material is reached at every point in the cross section. Formulas for calculating values of ultimate torque based on this method are also given in Table 15a.

When flanged shapes such as I's and channels are loaded in torsion, the calculation of stresses is usually much more complicated than for members with solid or tubular cross sections such as those shown in Table 15a, page 102. This is because the twisting of flanged members may be considerably affected by the tendency of the cross sections to "warp" or distort out of their original planes. When some cross sections are restrained against warping, the restraint modifies the distribution of shearing stress and also introduces longitudinal stresses in the member.[1] The problem of calculating these stresses is not frequently encountered, however, because members with solid or tubular cross sections are more efficient in resisting torsional loads and are usually chosen where this type of loading is involved.

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[1] See, for example, H. N. Hill, "Torsion of Flanged Members with Cross Sections Restrained Against Warping," *Technical Note* 888, National Advisory Committee for Aeronautics, 1943; also, S. Timoshenko, *Strength of Materials* Part II, Chapter VI, D. Van Nostrand Co., Inc., New York, 1947.

TABLE **15a**

Torsion Formulas

SOLID AND TUBULAR SECTIONS

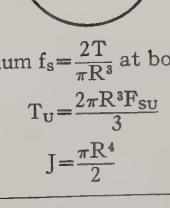
f_s = shear stress, kips per sq in., (formulas for f_s apply for stress not exceeding the shear yield strength)

T = torque, in.-kips

T_U = approximate ultimate torque, in.-kips

F_{SU} = ultimate shear strength, kips per sq in.

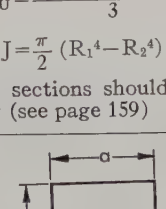
J = torsion constant,① in.⁴



Maximum $f_s = \frac{2T}{\pi R^3}$ at boundary

$T_U = \frac{2\pi R^3 F_{SU}}{3}$

$J = \frac{\pi R^4}{2}$



Maximum $f_s = \frac{2R_1T}{\pi(R_1^4 - R_2^4)}$ at boundary

$T_U = \frac{2\pi(R_1^3 - R_2^3)F_{SU}}{3}$

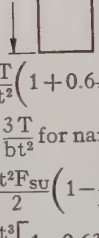
$J = \frac{\pi}{2}(R_1^4 - R_2^4)$

Thin-walled sections should be checked for buckling (see page 159)

Maximum $f_s = \frac{4.8T}{a^3}$ at midpoints of sides

$T_U = \frac{a^3 F_{SU}}{3}$

$J = 0.141a^4$



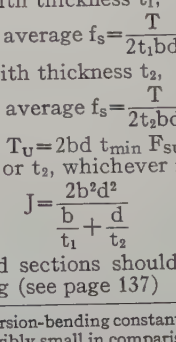
Maximum $f_s = \frac{3T}{bt^2}\left(1 + 0.6\frac{t}{b}\right)$ at midpoints of long sides

(approximately $\frac{3T}{bt^2}$ for narrow rectangles)

$T_U = \frac{bt^2 F_{SU}}{2}\left(1 - \frac{t}{3b}\right)$

$J = \frac{bt^3}{3}\left[1 - 0.63\frac{t}{b} + 0.052\left(\frac{t}{b}\right)^5\right]$

(approximately $\frac{bt^3}{3}$ for narrow rectangles)



For sides with thickness t_1,

average $f_s = \frac{T}{2t_1bd}$

For sides with thickness t_2,

average $f_s = \frac{T}{2t_2bd}$

$T_U = 2bd\ t_{min}\ F_{SU}$

($t_{min} = t_1$ or t_2, whichever is smaller)

$J = \frac{2b^2d^2}{\frac{b}{t_1} + \frac{d}{t_2}}$

Thin-walled sections should be checked for buckling (see page 137)

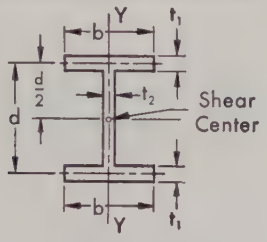
①See footnote on Table 15b regarding the torsion constant, J, and the torsion-bending constant, C_S. Formulas f C_S are not given in this table because for these cross sections, C_S is negligibly small in comparison to J.

TABLE
15b

Torsion Formulas

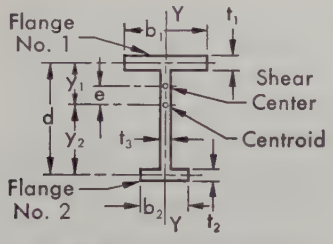
THIN-WALLED OPEN SECTIONS

J = torsion constant,① in.⁴
I_Y = moment of inertia of section about Y-axis, in.⁴
I_1 = moment of inertia of flange No. 1 about Y-axis, in.⁴
I_2 = moment of inertia of flange No. 2 about Y-axis, in.⁴
C_S = torsion-bending constant,① in.⁶
r_Y = radius of gyration of section about Y-axis, in.
r_X = radius of gyration of section about X-axis, in.
A_F = area of one flange, in.²
A = total area of section, in.²



$$J = \tfrac{1}{3}\,(2bt_1^3 + dt_2^3)$$

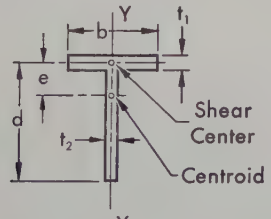
$$C_S = \frac{d^2 I_Y}{4}$$



$$J = \tfrac{1}{3}\,(b_1 t_1^3 + b_2 t_2^3 + dt_3^3)$$

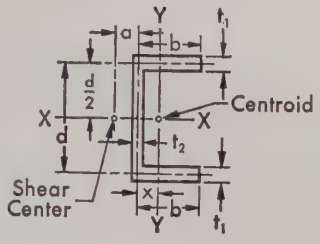
$$C_S = \frac{d^2 I_1 I_2}{I_Y}$$

$$e = \frac{y_1 I_1 - y_2 I_2}{I_Y}$$



$$J = \tfrac{1}{3}\,(bt_1^3 + dt_2^3)$$

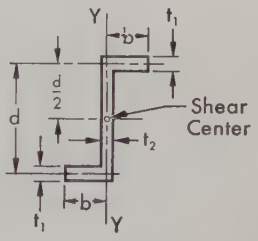
$$C_S = 0$$



$$J = \tfrac{1}{3}\,(2bt_1^3 + dt_2^3)$$

$$C_S = \frac{d^2 I_Y}{4}\left[1 - \frac{x(a-x)}{r_y^2}\right]$$

$$a = \frac{xd^2}{4r_x^2}$$



$$J = \tfrac{1}{3}\,(2bt_1^3 + dt_2^3)$$

$$C_S = \frac{d^2 I_Y}{4}\left(1 - \frac{3A_F}{2A}\right)$$

①The torsion constant, J, is a measure of the stiffness of a member in pure twisting. The torsion-bending constant, C_S, is a measure of the resistance to rotation that arises because of restraint of warping of the cross section. These constants are used in calculating the buckling strength of beams and columns (see pages 116 to 119) and in determining the angle of twist in members subjected to a torque (see page 192). Their values for structural shapes are listed in Tables 40 to 52.

Example 4. Find the factor of safety against yielding and ultimate strength for a 1½ in. square 6061-T6 alloy rolled bar carrying a torque of 8 in.-kips. From Table 4d, page 54, the shear properties for this material are: yield strength=20 kips per sq in.; ultimate strength=25 kips per sq in.

The shear stress resulting from an applied torque of 8 in.-kips is given by (Table 15a, page 102)

$$f_s=\frac{4.8T}{a^3}$$

$$=\frac{4.8\times 8}{(1.5)^3}=11.4 \text{ kips per sq in.}$$

Thus the factor of safety on yielding is $\frac{20}{11.4}=1.76$.

Since the above formula does not apply for stresses exceeding the yield strength, it cannot be used to determine factor of safety on ultimate strength. To calculate the ultimate strength, use the formula (Table 15a, page 102):

$$T_U=\frac{a^3F_{SU}}{3}$$

$$=\frac{(1.5)^3\times 25}{3}=28.1 \text{ in.-kips.}$$

The factor of safety on ultimate strength is $\frac{28.1}{8}=3.51$

When a flanged shape such as an I-section is subjected to transverse loads, it is desirable to avoid the introduction of any torque that might arise because of eccentricity of the load. In most cases this is not a problem because beams are usually supported against lateral rotation at the points of load application. Where no such support is provided, however, the line of action of the load should pass through the point in the cross section known as the "shear center" in order that no torque will be introduced. For doubly symmetrical sections, such as an ordinary I-beam, or for sections symmetrical about a point, such as a Z-section, the shear center is at the centroid. The location of the shear center for some other cross sections may be found from the formulas in Table 15b, page 103.

Combined Stresses

The mechanical properties of materials are usually determined with the test specimens loaded in simple tension, compression or shear. In the load-carrying parts of machines and structures, however, these simple states of stress are frequently superimposed on each other to form a system of "combined stresses." The effect of these combined stresses on the strength of the part may be predicted approximately by means of the "maximum shear stress" rule. According to this rule, yielding will occur under any system of

stresses when the maximum shear stress reaches a value equal to one-half the tensile yield strength as determined in axial tension. Similarly, the rule predicts ultimate failure under combined stresses when the maximum shear stress reaches a value equal to one-half the ultimate tensile strength.

The maximum shear stress in any plane may be found by means of the formulas in Table 16, page 106. In using these formulas, it should be remembered that any actual stress condition involves three dimensions. It may be necessary, therefore, to examine the shear stress in more than one plane to make sure that the largest value has been found.

Example 5. Find the factor of safety against yielding for the 1½-in. square 6061-T6 rolled bar used in Examples 3 and 4, pages 98 and 104, if the bar must carry a combined bending moment of 13 in.-kips and torque of 8 in.-kips.

From Example 3, page 98, the maximum bending stress caused by the 13 in.-kip bending moment is 23.1 kips per sq in.

From Example 4, page 104, the maximum shear stress caused by the torque of 8 in.-kips is 11.4 kips per sq in. (at the midpoint of each side).

At the midpoints of the top and bottom sides, the bending stress and torsion stress both attain maximum values. In a plane parallel to the surface of the bar at one of these points, the stress system is represented by case 4 of Table 16, page 106. The maximum shear stress in this plane is

$$(f_s)_{max} = \sqrt{\left(\frac{f_1}{2}\right)^2 + f_s^2}$$

$$= \sqrt{\left(\frac{23.1}{2}\right)^2 + (11.4)^2} = 16.2 \text{ kips per sq in.}$$

In this case this is the maximum shear stress in the bar. In more complicated problems it may be necessary to examine the shear stress on other planes to make sure that the largest value has been found.

The minimum tensile yield strength for this material (Table 4d, page 54) is 35 kips per sq in. By the maximum shear stress rule, the shear stress at which yielding will occur under combined stresses is 35/2=17.5 kips per sq in. So the factor of safety against yielding is 17.5/16.2=1.08. (Note that the factors of safety against yielding for the bending load and the torque separately were 1.52 and 1.76, respectively.)

Creep and Stress-Rupture

If a member is subjected to steady stress for a long period of time at elevated temperatures, it may slowly deform and perhaps eventually rupture. This deformation under constant stress is known as "creep," and the ultimate failure is called "stress-rupture." These phenomena

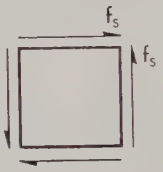
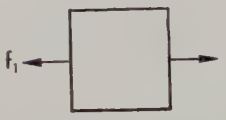
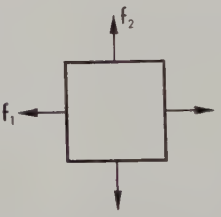
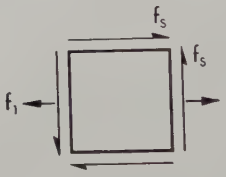
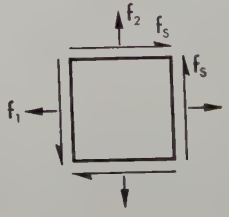
TABLE 16

Maximum Shear Stress

f_s = shear stress, kips per sq in.

f_1 and f_2 = normal stresses, kips per sq in.

$(f_s)_{max}$ = maximum shear stress in plane of sketch, kips per sq in.

1 Pure shear, f_s		$(f_s)_{max}=f_s$
2 Simple tension or compression, f_1		$(f_s)_{max}=\frac{f_1}{2}$
3 Two normal stresses, f_1 and f_2 at right angles to each other (stresses f_1 and f_2 are either tension or compression, tension being considered positive and compression negative)		$(f_s)_{max}=\frac{f_1-f_2}{2}$
4 One normal stress, f_1, and shear stress, f_s, on planes parallel and perpendicular to f_1		$(f_s)_{max}=\sqrt{\left(\frac{f_1}{2}\right)^2+f_s^2}$
5 Two normal stresses, f_1 and f_2, and shear stress, f_s, on planes parallel and perpendicular to f_1 and f_2		$(f_s)_{max}=\sqrt{\left(\frac{f_1-f_2}{2}\right)^2+f_s^2}$

are generally not important factors in design because no perceptible creep will occur at the usual working stresses under ordinary temperature conditions. However, where a high stress is applied for long periods of time at elevated temperatures, it may be necessary to take into account not only the static properties at elevated temperatures as listed in Table 8, pages 76 to 82, but also the creep and stress-rupture characteristics of the metal.①

Fatigue

When a member is subjected to many cycles of repeated loading, it may eventually fail, even though the maximum stress in any cycle is considerably below the static strength of the material. This is called fatigue failure. The failure occurs by the formation of a minute crack which may gradually extend until the strength of the part is so reduced that the part ruptures completely.

Fatigue life is governed by the peak stresses at points of stress concentration rather than by the nominal stresses used in ordinary design. When a fatigue failure occurs in a structure, it is almost always traceable to some stress raiser such as a notch, hole or sharp re-entrant corner. Concentrations of stress at such points can frequently be alleviated by proper design, fabrication and maintenance, resulting in greatly improved fatigue life.②

Unfortunately, present knowledge of fatigue is not sufficiently advanced to permit precise design for a specified life, even in simple parts. As indicated by the data in Tables 9 and 10, pages 83 and 84, which show the fatigue strengths of the various aluminum alloys determined with polished specimens, the number of repetitions of load or cycles of stress required to produce failure depends upon the stress level and also upon the range of stress. In many practical instances, it is not possible to predict the maximum values of these quantities accurately. Another difficulty is that the load cycles are often not repeated exactly but are actually combinations of many different load cycles. Additional complications are introduced by the effects of such factors as the magnitude of residual stress, the surface condition of the piece and plastic yielding.

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①Further information on creep and stress-rupture of aluminum alloys can be found in the following references:

1. *Strength of Metal Aircraft Elements*, ANC-5 Bulletin, issued by the Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria, June, 1951.
2. J. E. Dorn and T. E. Tietz, "Creep and Stress-Rupture Investigations on Some Aluminum Alloy Sheet Metals," *Proceedings*, American Society for Testing Materials, Vol. 49, 1949, p. 815.
3. O. D. Sherby, T. E. Tietz, and J. E. Dorn, "The Creep Properties of Some Forged and Cast Aluminum Alloys," *Proceedings*, American Society for Testing Materials, Vol. 51, 1951, p. 964.
4. R. R. Kennedy, "Creep Characteristics of Aluminum Alloys," *Proceedings*, American Society for Testing Materials, Vol. 35, Part II, 1935, p. 218.

②R. L. Templin and E. C. Hartmann, "How to Design for Repeated Load," *Iron Age*, Mar. 27, 1952.

The fact that it is not possible at present to predict fatigue life within close limits should not discourage the engineer from trying to obtain satisfactory resistance to fatigue action. The charts in Figures 2 and 3, pages 108 and 109, show fatigue test results on actual riveted joints arranged in a convenient manner for estimating the fatigue life of riveted assemblies. The curves are representative of what may be expected on normal riveted structures free from unusually severe stress raisers such as sharp re-entrant corners. In using these curves, it is not necessary to apply any additional stress concentration factors because those represented by normal riveted construction are already included. It is necessary, however, to take into account the effects of eccentric loadings or secondary bending which may occur in members being designed for fatigue.

Comparison of Figures 2 and 3, pages 108 and 109, with the data in Table 10, page 84, shows that the ratio of the smooth specimen fatigue strength to the strength of riveted joints of the type tested ranges from about 2.5 to 3.4 at the long-life end of the fatigue

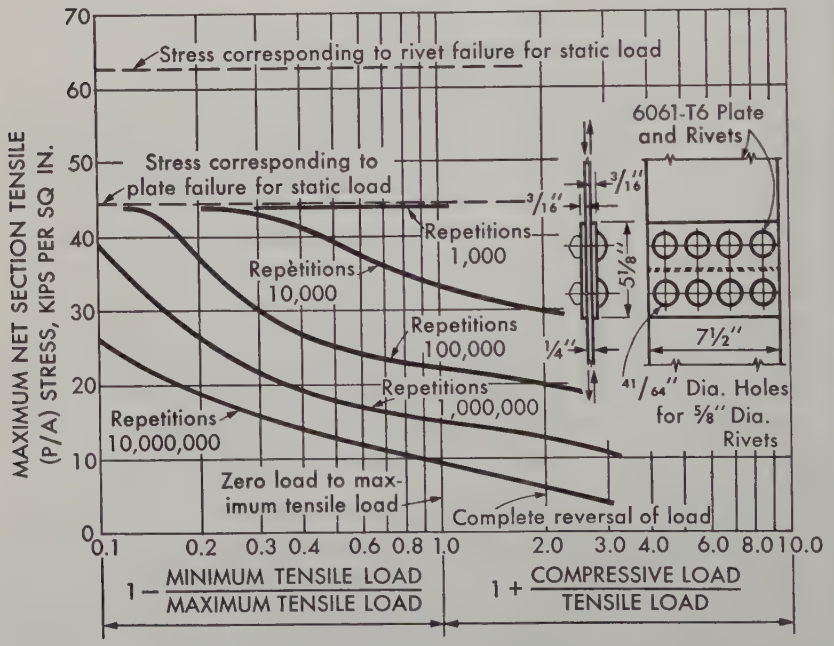

Fig. 2—Approximate Fatigue Life of Riveted Joints of 6061-T6 Alloy as Determined by Axial Load Tests on Double-Strap Butt Joints

curves. These fatigue strength reduction factors decrease as the number of cycles is reduced, and they approach unity at around 10,000 to 1,000 cycles for the stress ratios under consideration. Fatigue strength reduction factors such as these may be useful in designing for fatigue in alloys not represented in Figures 2 and 3, pages 108 and 109.

In designing for fatigue action, it should be remembered that the maximum combination of loadings used in ordinary static design (dead load, maximum live load, maximum impact, etc.) rarely occurs in actual service and is of little or no interest from the standpoint of fatigue. In fatigue design, one is interested usually only in the steady dead load with a superimposed and repeatedly applied live load, the magnitude of which is consistent with normal operating conditions. Care must be taken not to over-estimate grossly the number of cycles for given load applications. Some machine parts, of course, quickly accumulate millions of cycles of load application, but many other engineering assemblies accumulate load cycles at a

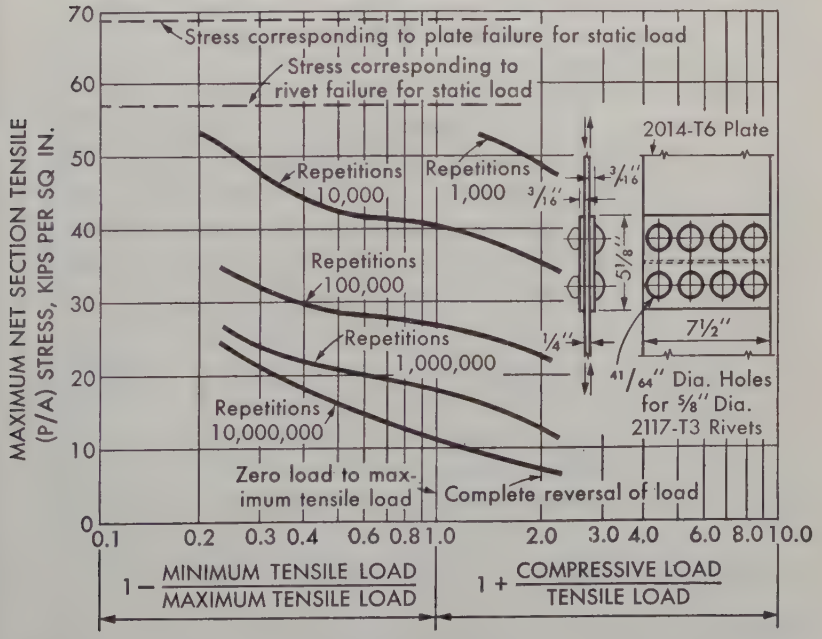

Fig. 3—Approximate Fatigue Life of Riveted Joints of 2014-T6 Alloy as Determined by Axial Load Tests on Double-Strap Butt Joints

much lower rate. A storage vessel emptied and filled once a day, for example, accumulates only 7,300 cycles of loading in twenty years.

Example 6. Check the 6061-T6 tension hanger shown in the sketch in Example 1, page 95, to determine its probable life when loaded repeatedly from an axial dead load of 20 kips to a maximum axial dead load plus live load of 70 kips.

Dead load plus live load net-section stress $= \frac{70}{4.40} = 15.9$ kips per sq in.

Ratio: $\frac{\text{minimum tensile load}}{\text{maximum tensile load}} = \frac{20}{70} = 0.286.$

Use Figure 2, page 108, since difference in hole size and rivet alloy is not such as to affect fatigue strength of joint.

The abscissa to be used in Figure 2 is $(1-0.286)=0.714$.

Using this abscissa and an ordinate of 15.9 in Figure 2, one estimates a life of about 1,000,000 cycles of axial loading from 20 kips to 70 kips.

BUCKLING

Strength members must be checked not only against yielding and fracture, as described in the preceding section, but also against various types of buckling. Buckling is produced by compression or shear stresses and may take many different forms. Sidewise bending, twisting and wrinkling are common forms of buckling.

Some types of buckling are more significant than others. When a column, for example, reaches its buckling load, collapse will ordinarily be imminent. The designer should provide about the same factor of safety against this type of buckling as he would against failure by tensile fracture. Less significant types of buckling are exemplified by local wrinkles that appear in thin portions of otherwise sturdy sections. In such instances, the amount of metal affected by the buckling is often such a small portion of the total that the member as a whole is in no danger of collapse. Naturally, a smaller factor of safety can be used in the case of this type of buckling.

In this discussion, buckling will be treated under several headings such as columns, beams and girders, flat plates, etc. In each case an attempt will be made to indicate whether the type of buckling is likely to precipitate complete failure of the member. Formulas will be given for the buckling stresses and rules suggested for calculating the effective area of a part of a member that has buckled but is still capable of carrying load.

Columns

Columns may fail by bending, twisting or by local buckling of individual elements of the cross section. Only the first mode of

failure will be discussed under this heading, the others being treated in later sections.

Bending failure of columns is the type of failure usually understood when the expression "column strength" is used without qualification. The column strength of aluminum alloys, as with other metals, is a function not only of the properties of the material but also of the "effective slenderness ratio" of the member. The effective slenderness ratio is the ratio KL/r, in which L is the length of the column, r is the corresponding radius of gyration and K is a factor that represents the effect of the end conditions of the column.

A typical relationship between column strength and effective slenderness ratio for aluminum alloys is illustrated by Figure 4 below. For relatively long axially loaded columns, the ultimate strength, f_C, in kips per sq in. is

$$f_C = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2} \qquad (1)$$

This expression applies when KL/r is greater than the value C, as shown in Figure 4 below. When KL/r is less than C, the relationship between the column strength and effective slenderness ratio is

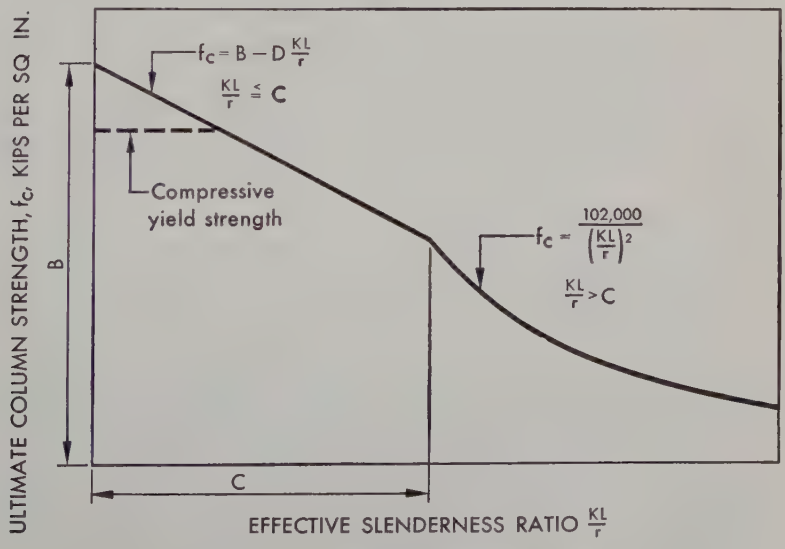

Fig. 4—Typical Column Strength Curve for Aluminum Alloys

$$f_c = B - D\frac{KL}{r} \qquad (2)$$

The constants B, D and C depend upon the mechanical properties of the material. Values of these constants corresponding to minimum mechanical properties of the various aluminum alloy products are listed with the mechanical properties in Table 4, pages 42 to 66.

For some aluminum alloys and products, the straight line represented by formula (2) is tangent to the curve for long columns, formula (1). For others, the line intersects the curve at an angle as in Figure 4, page 111.

The factor 102,000 in formula (1) represents the quantity $\pi^2 E$, where E, the modulus of elasticity, is assigned an average value of about 10,300 kips per sq in. More precise values of modulus of elasticity for the various alloys are listed in Table 3, pages 35 to 38, and may be used in place of 10,300 kips per sq in. if desired.

Table 17, page 113, gives values of ultimate column strength calculated from formula (1) for various effective slenderness ratios. These values are applicable only when KL/r is greater than the constant C for the particular alloy and product in question.

For very short, compact columns, it may be desirable to maintain a certain factor of safety against yielding. In this event, the column strength curve should be cut off at a value of f_c corresponding to the compressive yield strength of the material, as indicated in Figure 4, page 111. As previously pointed out, however, yielding does not necessarily precipitate collapse of short, compact members of aluminum alloy.

The value of the factor K depends upon whether or not the ends of the column are free to tip or rotate as the column deflects. Some values of K for different types of end conditions are as follows:

For both ends completely fixed.....K=0.5
For one end fixed and one end pinned.....K=0.7
For both ends pinned (frictionless pins).....K=1.0
For one end fixed and one end free (cantilever compression member).....K=2.0

In selecting a value of K corresponding to a given set of end conditions, it may be helpful to think of KL, the "effective length," as the portion of the member which functions as though it were pin-ended, that is, the length between points of contra-flexure when the member is in its deflected position. This deflected position should be visualized in terms of the conditions that would exist just before failure.

TABLE 17

Values of Column Strength in Elastic Stress Range

Note: These values apply only when $\frac{KL}{r}$ is greater than the constant C for the alloy in question—see Table 4, pages 42 to 66.

$$f_c = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2}$$

f_c = column strength (see note above), kips per sq in.

$\frac{KL}{r}$ = effective slenderness ratio

$\frac{KL}{r}$	f_c	$\frac{KL}{r}$	f_c	$\frac{KL}{r}$	f_c
35	83.3	65	24.1	110	8.4
36	78.7	66	23.4	112	8.1
37	74.5	67	22.7	114	7.8
38	70.6	68	22.1	116	7.6
39	67.1	69	21.4	118	7.3
40	63.8	70	20.8	120	7.1
41	60.7	71	20.2	125	6.5
42	57.8	72	19.7	130	6.0
43	55.2	73	19.1	135	5.6
44	52.7	74	18.6	140	5.2
45	50.4	75	18.1	145	4.9
46	48.2	76	17.7	150	4.5
47	46.2	77	17.2	155	4.2
48	44.3	78	16.8	160	4.0
49	42.5	79	16.3	165	3.7
50	40.8	80	15.9	170	3.5
51	39.2	82	15.2	175	3.3
52	37.7	84	14.5	180	3.1
53	36.3	86	13.8	185	3.0
54	35.0	88	13.2	190	2.8
55	33.7	90	12.6	200	2.6
56	32.5	92	12.1	210	2.3
57	31.4	94	11.5	220	2.1
58	30.3	96	11.1	230	1.9
59	29.3	98	10.6	240	1.8
60	28.3	100	10.2	250	1.6
61	27.4	102	9.8	260	1.5
62	26.5	104	9.4	270	1.4
63	25.7	106	9.1	280	1.3
64	24.9	108	8.7	290	1.2

When a column is a part of a framed structure, a precise determination of the end conditions may require an analysis of the entire framework, or at least of those members in the immediate vicinity of the column in question. Methods for making such an analysis are discussed in current technical literature.[1] In the absence of a detailed analysis, the designer may estimate the end conditions and the corresponding value of K, keeping in mind the following general rules.

The ends of a column should be considered as pinned if (a) the end connections are not capable of offering much resistance to rotation, (b) the members into which the column is framed are relatively flexible in comparison to the column or (c) the members into which the column is framed are in compression and tend to buckle at about the same load as the column. An example of a connection that provides little resistance to rotation is a single gusset plate when failure of the column is in a direction perpendicular to the plane of the plate. Such a gusset plate is usually so flexible that the column should be considered as pin-ended. An example of a compression member that is not greatly restrained by the surrounding structure, even if the connections are rigid, is a section of a chord of a latticed tower or boom, considered as a column with a length equal to the distance between panel points. The lattice members are usually too slender in comparison to the chords to furnish much resistance to rotation, and the adjacent sections of the chord do not appreciably restrain each other because they tend to buckle at about the same load. As a result, the chord behaves very nearly as though it were hinged at the panel points. A value of K of 1.0 or 0.9 should be used for such a member.

When it is apparent that the surrounding structure is rigid enough to offer some restraint to a compression member, use of a K factor of 1.0 will be safe but may result in a member that is larger than necessary. Frequently K is assumed to be 0.75 in these cases. Values smaller than 0.75 should not be used unless a detailed analysis of the structure demonstrates convincingly that the smaller value is justified for the member in question. The fixed-end condition can be approached only if the column bears flat against a very rigid surface or is rigidly framed into much stiffer members.

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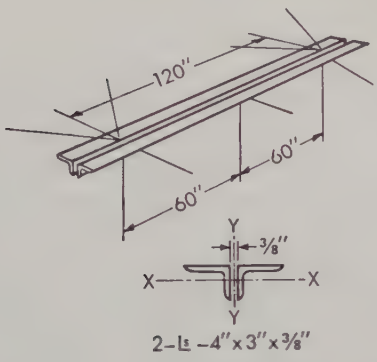
[1] For example, Friedrich Bleich, *Buckling Strength of Metal Structures*, Chapter VII, McGraw-Hill Book Co., Inc., New York, 1952.

A column should always be considered to be on the point of collapse as it approaches the critical stress indicated by the column formula. An adequate factor of safety should always be used with the column formulas, and care should be taken not to use too low a value of the factor K.

Example 7. Design the compression chord of a truss for an axial load of 52 kips using a factor of safety of 2.5. The chord is supported vertically at panel points 60 inches apart and horizontally at every other panel point.



Try two angles 4" × 3" × 3/8" 6061-T6 alloy, area = 4.98 sq in.

Calculated stress $= \frac{P}{A} = \frac{52}{4.98}$ = 10.4 kips per sq in.

Axis X,
L = 60", r = 0.86", assume K = 0.8

$$\frac{KL}{r} = \frac{0.8 \times 60}{0.86} = 56$$

Axis Y,
L = 120", r = 1.91", assume K = 0.8

$$\frac{KL}{r} = \frac{0.8 \times 120}{1.91} = 50$$

Greatest value of $\frac{KL}{r}$ is 56, about Axis X.

From Table 4c, page 52, C=63 for 6061-T6 standard structural shapes. Since $\frac{KL}{r} < 63$, use formula (2) to calculate column strength. Constants B and D are obtained from Table 4c.

$$f_C = B - D\frac{KL}{r} = 38.3 - 0.202 \times 56 = 27 \text{ kips per sq in.}$$

Factor of safety $= \frac{27}{10.4} = 2.6$.

Since this factor of safety is greater than 2.5, the member selected is satisfactory.

Use of Equivalent Slenderness Ratio

For types of buckling other than bending failure of columns (for example, lateral buckling of beams, local buckling of plates, etc.), it is convenient to calculate the buckling load from formulas (1) and (2) for column buckling, pages 111 and 112, by substituting in the formulas an "equivalent slenderness ratio," KL/r, which depends on the proportions of the member and the type of buckling involved. The equivalent slenderness ratio is simply the slenderness ratio of a column that would buckle at the same stress as the member in question.

The reason for using this method is that it is easy to take account of the effect of plastic yielding in this way. Otherwise, it would be necessary to write a different set of formulas for plastic buckling for each type of instability problem. By finding the critical stress in terms of the strength of an equivalent column, however, it is possible to use one set of formulas to determine compressive buckling stresses for a wide variety of problems.

In some cases an "equivalent radius of gyration," r, is calculated and combined with the length of the member to determine the equivalent slenderness ratio.

Twisting Failure of Columns

Most conventional columns are so stiff in torsion that the possibility of buckling by twisting need not be considered. This includes all box-section columns, closed tubes of any shape and solid shapes such as rounds and rectangles. Flanged columns whose cross sections are symmetrical about a point, such as I, H and Z-section columns, are not likely to fail by twisting unless they are supported in such a manner that the effective length for twisting failure is much greater than the effective length for failure by bending.

Twisting-type failures are most apt to occur in the case of torsionally weak sections that are unsymmetrical or have only one axis of symmetry, such as angles, tees and thin-walled channels. These members tend to fail by combined twisting and bending. In the case of channels of conventional cross section, however, this type of buckling will generally not reduce the load-carrying capacity appreciably below the critical load for bending failure in the weak direction. In the case of angles having equal legs, the critical load for twisting failure is essentially the same as the load that causes local buckling of the outstanding legs. This load may be calculated as described in the section on local buckling, pages 130 to 137.

If a member is susceptible to twisting failure, the critical load may be calculated from formulas (1) and (2) for bending failure, pages 111 and 112, by making use of an equivalent radius of gyration, r_t. The equivalent radius of gyration is divided into the effective length for twisting failure, KL, to determine the equivalent slenderness ratio. The equivalent slenderness ratio is then substituted in the column formula (1) or (2) to find the buckling stress.

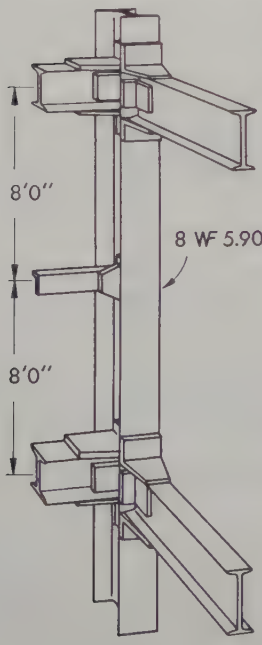
The equivalent radius of gyration for twisting failure of a member whose cross section is symmetrical about a point (such as an I or Z) can be calculated from the following formula:

$$r_t^2 = \frac{C_s + 0.038J(KL)^2}{I_x + I_y} \qquad (3)$$

where r_t = equivalent radius of gyration for twisting failure, in.,
C_s = torsion-bending constant, in.^{6} (see Table 15b, page 103),
$I_x + I_y$ = sum of moments of inertia about perpendicular axes through centroid, in.^{4},
J = torsion constant, in.^{4}, (see Tables 15a and 15b, pages 102 and 103),
L = length of portion of member in which twisting can occur, in.,
K = factor representing end condition for twisting failure.

Values of C_s and J, as well as I_x and I_y, for structural shapes may be found in Tables 40 to 52, pages 212 through 234. The factor K is similar to K for bending failure, except that in twisting failures the ends are considered "fixed" ($K = 0.5$) if they can neither rotate about the longitudinal axis of the member nor warp out of their original planes. Ends are "pinned" ($K = 1.0$) if the end cross sections are free to warp but not to rotate. An end is "free" if it can both rotate and warp. A member having one end "free" and one "fixed" would have a value of K of 2.0.

Example 8. Determine the factor of safety for the 2014-T6 column shown in the sketch when the compressive load is 30 kips. The member framed into the center of the column supports it against bending normal to the web but does not prevent bending parallel to the web or twisting.



Failure by bending in the plane of the web.

$$L = 192''$$
$$r = 3.36''$$
Assume $K = 0.8$
$$\frac{KL}{r} = \frac{0.8 \times 192}{3.36} = 45.7$$

Failure by bending normal to the plane of the web.

$$L = 96''$$
$$r = 1.22''$$
Assume $K = 0.8$
$$\frac{KL}{r} = \frac{0.8 \times 96}{1.22} = 63.0$$

Failure by twisting.

$$L = 192''$$
Assume $K = 0.8$
From formula (3),
$$r_t^2 = \frac{110 + 0.038 \times 0.135 (0.8 \times 192)^2}{56.73 + 7.44}$$
$$r_t = 1.90$$
$$\frac{KL}{r_t} = \frac{0.8 \times 192}{1.90} = 80.8$$

The largest value of $\frac{KL}{r}$ is 80.8 for failure by twisting. From Table 4b, page 50, C=50. Since $\frac{KL}{r} > 50$, use formula (1), page 111, to calculate column strength.

$$f_C = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2} = \frac{102{,}000}{(80.8)^2} = 15.6 \text{ kips per sq in.}$$

$$\text{Average compressive stress} = \frac{30}{5.02} = 5.98 \text{ kips per sq in.}$$

$$\text{Factor of safety} = \frac{15.6}{5.98} = 2.61$$

This handbook does not cover methods for dealing with torsional failure of unsymmetrical sections which may fail by combined twisting and bending. The designer concerned with members for which this type of failure is important may wish to refer to some of the textbooks or technical articles that treat this subject.[1]

Buckling of Beams and Girders

The strength of single-web beams and girders that do not have continuous lateral support is generally limited by buckling, involving lateral bending and twisting. The value of the buckling stress on the gross area of the compression flange may be determined from the column formulas (1) and (2), provided that the proper value of equivalent radius of gyration is used (see pages 115 and 116). The equivalent radius of gyration for a beam may be determined from one of the following formulas:

For beams and girders of symmetrical I, channel or rectangular cross sections, supported at the ends of the length L,

$$r_{b1}^2 = \frac{\sqrt{I_y}}{S_c}\sqrt{C_s + 0.038\ J\ (KL)^2} \qquad (4a)$$

For I-beams with unequal flanges and T-sections, supported at the ends of the length L,

$$r_{b2}^2 = \frac{I_y}{S_c}\left(e + \sqrt{e^2 + \frac{1}{I_y}[C_s + 0.038\ J\ (KL)^2]}\right) \qquad (4b)$$

For cantilever I-sections, channels and rectangular beams with a concentrated load at the free end,

$$r_{b3}^2 = 1.28\ r_{b1}^2 \qquad (5a)$$

[1] For example, Friedrich Bleich, *Buckling Strength of Metal Structures*, Chapter III, McGraw-Hill Book Co., Inc., New York, 1952.

For cantilever I-sections, channels and rectangular beams with a uniformly distributed load,

$$r_{b4}^2 = 2.05\ r_{b1}^2 \qquad (5b)$$

where r_b = equivalent radius of gyration of beam, in.

I_y = moment of inertia of beam about principal axis parallel to web, in.^{4}

S_c = section modulus for beam about axis normal to web (compression side), in.^{3}

C_s = torsion-bending constant, in.^{6} (see Table 15b, page 103. For rectangular section beams, C_s may be considered to be 0 in formulas 4a, 5a and 5b.)

J = torsion constant, in.^{4} (see Tables 15a and 15b, pages 102 and 103)

L = laterally unsupported length of beam, in.

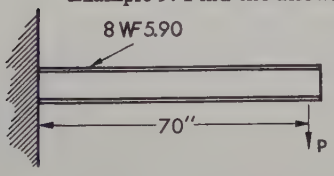
K = factor representing lateral restraint at ends of laterally unsupported length, same as for columns except that for cantilever beams, formulas (5a) and (5b), use K = 1.0.

e = distance from centroid to shear center, in. (see page 104 and Table 15b, page 103). Distance e is positive if the shear center lies between the centroid and the compression flange and negative if the shear center is between the centroid and the tension flange.

The value of equivalent radius of gyration is used with KL, the effective laterally unsupported length, to determine the equivalent slenderness ratio. This slenderness ratio is then substituted in the column formula for the alloy in question to arrive at the buckling stress for the beam.

Table 18, pages 120 to 125, gives values of equivalent slenderness ratio for various lengths of I-beams, wide-flange sections and channels. The values of r_b used in calculating the equivalent slenderness ratios in Table 18 were determined from formula (4a).

The values of C_s and J for structural shapes are included in Tables 40 to 52, pages 212 through 234. For other shapes, the values of C_s and J may be calculated as shown in Tables 15a and 15b, pages 102 and 103. The formulas for C_s of I-sections in Table 15b also apply to plate girders. The value of J for plate girders may be taken to be the sum of the J values for the individual elements of the girder, except that when several cover plates are riveted together the parts of the plates between the outside rivet lines may be considered as one solid piece in calculating J.



Example 9. Find the allowable load on the 2014-T6 alloy wide flange section cantilever beam shown in the sketch, using a factor of safety of 2.5 against buckling.

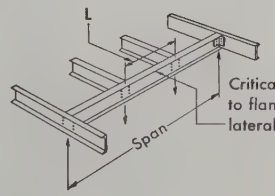
By interpolation from Table 18c, page 122, $KL/r_{b1} = 46.7$ (using K = 1.0).

Continued on page 126)

TABLE 18a

Values of Equivalent Slenderness Ratio for Beams

I-BEAMS (AMERICAN STANDARD)



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

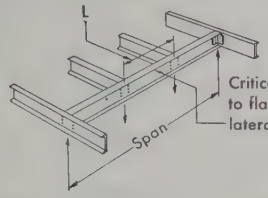
r_{b1} = equivalent radius of gyration, in., defined on page 118

I-Beams				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Depth, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.³	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
3	0.170	1.96	1.68	28.3	45.7	58.0	67.9	76.5	94.3	109.1	122.1	133.9	144.6	154.7
3	0.349	2.59	1.95	25.4	39.6	49.6	57.8	64.9	79.8	92.2	103.2	113.1	122.2	130.6
4	0.190	2.64	3.03	26.9	45.7	59.2	70.0	79.2	98.2	113.8	127.5	139.9	151.2	161.7
4	0.326	3.28	3.39	25.4	42.2	54.0	63.5	71.6	88.4	102.5	114.7	125.8	135.9	145.3
5	0.210	3.43	4.90	24.8	43.8	57.9	69.1	78.5	97.9	113.9	127.7	140.1	151.5	162.1
5	0.494	5.10	6.09	22.5	37.5	48.1	56.6	63.9	79.0	91.5	102.4	112.3	121.4	129.8
6	0.230	4.30	7.36	23.0	41.9	56.6	68.4	78.4	98.6	115.0	129.1	141.8	153.4	164.2
6	0.465	5.96	8.77	21.7	37.9	49.8	59.3	67.8	83.7	97.2	109.0	119.6	129.3	138.3
7	0.250	5.27	10.48	21.3	39.6	54.2	66.2	76.3	96.7	113.1	127.2	139.9	151.4	162.1
7	0.450	6.92	12.12	20.6	37.2	49.9	60.0	68.6	86.1	100.3	112.6	123.6	133.7	143.1
8	0.270	6.35	14.39	19.8	37.3	51.8	64.0	74.3	95.1	111.7	126.0	138.7	150.2	160.9
8	0.532	8.81	17.18	19.0	34.7	47.0	56.8	65.2	82.1	95.7	107.6	118.2	127.8	136.8
9	0.290	7.51	19.09	18.4	35.2	49.5	61.6	72.0	93.0	109.7	124.0	136.6	148.1	158.7
10	0.310	8.76	24.68	17.3	33.2	47.1	59.0	69.4	90.4	107.0	121.2	133.8	145.1	155.6
10	0.594	12.10	29.41	16.8	31.6	43.7	53.8	62.3	79.6	93.4	105.2	115.8	125.4	134.3
12	0.350	10.99	36.35	16.3	31.6	45.4	57.5	68.2	90.0	107.3	122.0	135.0	146.6	157.4
12	0.687	17.28	50.81	14.8	28.1	39.3	48.7	56.8	73.0	85.9	96.9	106.8	115.7	123.9

TABLE
18b

Values of Equivalent Slenderness Ratio for Beams

CHANNELS (AMERICAN STANDARD)



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

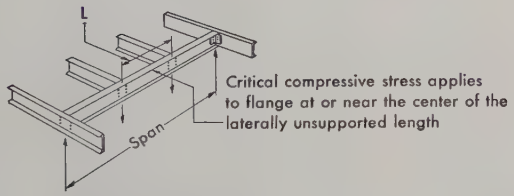
r_{b1} = equivalent radius of gyration, in., defined on page 118

Channels				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Depth, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.[3]	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
3	0.170	1.42	1.10	33.8	51.8	64.6	75.1	84.2	103.4	119.5	133.7	146.5	158.3	169.2
3	0.356	2.07	1.38	27.8	41.5	51.4	59.6	66.8	82.0	94.7	106.0	116.1	125.4	134.1
4	0.180	1.85	1.92	33.4	53.7	68.1	79.6	89.6	110.4	127.7	143.0	156.7	169.3	181.1
4	0.320	2.50	2.29	29.8	46.7	58.6	68.3	76.7	94.3	109.1	122.0	133.7	144.5	154.5
5	0.190	2.32	3.00	31.9	53.6	69.1	81.4	91.9	113.8	131.9	147.7	161.9	175.0	187.2
5	0.472	3.97	4.17	26.3	41.5	52.2	60.8	68.4	84.1	97.3	108.9	119.3	128.9	137.8
6	0.200	2.83	4.37	30.1	52.3	68.7	81.7	92.7	115.3	133.9	150.1	164.7	178.0	190.4
6	0.437	4.48	5.80	26.6	43.9	56.1	65.9	74.3	91.8	106.3	119.0	130.5	141.0	150.8
7	0.210	3.38	6.08	28.2	50.4	67.2	80.6	91.9	115.0	133.8	150.2	164.8	178.3	190.7
7	0.524	5.96	8.64	24.6	41.1	52.9	62.3	70.3	87.0	100.8	112.9	123.8	133.8	143.0
8	0.250	4.25	8.46	26.2	47.8	64.6	78.1	89.6	112.7	131.5	147.8	162.3	175.6	188.0
8	0.487	6.48	10.99	24.1	42.0	55.1	65.5	74.3	92.4	107.3	120.3	132.0	142.7	152.6
9	0.230	4.60	10.60	24.9	46.3	63.6	77.7	89.6	113.7	133.1	149.8	164.7	178.3	190.8
9	0.612	8.65	15.75	22.1	38.5	50.5	60.0	68.1	84.7	98.4	110.3	121.0	130.8	140.0
10	0.240	5.28	13.47	23.5	44.2	61.5	75.8	87.9	112.5	132.1	148.9	163.9	177.5	190.1
10	0.673	10.37	20.69	20.9	36.8	48.6	58.0	66.0	82.2	95.6	107.2	117.6	127.2	136.1
12	0.300	7.41	21.97	20.8	39.7	56.0	69.8	81.7	105.7	124.9	141.2	155.6	168.8	180.9
12	0.632	12.10	29.94	19.5	35.9	48.8	59.3	68.2	86.2	100.7	113.2	124.4	134.6	144.1
15	0.400	11.71	41.97	16.7	32.3	46.2	58.4	69.0	90.8	108.1	122.8	135.8	147.4	159.0
15	0.716	17.28	53.82	16.1	30.5	42.6	52.8	61.6	79.1	93.2	105.2	115.8	125.5	134.5

TABLE 18c

Values of Equivalent Slenderness Ratio for Beams

WIDE-FLANGE SECTIONS (INCLUDING H-BEAMS)



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

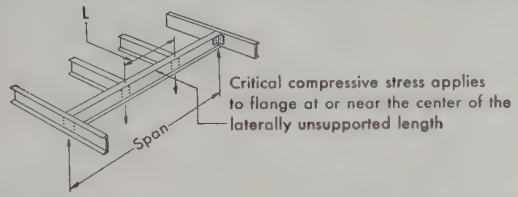
r_{b1} = equivalent radius of gyration, in., defined on page 118

Wide-Flange Sections				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Nominal Depth and Width, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.^{3}	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
2x2	0.094	0.78	0.481	33.3	56.5	73.1	86.3	97.6	120.9	140.2	157.1	172.3	186.2	199.1
2x2	0.188	1.43	0.782	27.8	42.6	53.1	61.7	69.2	85.0	98.2	109.9	120.4	130.1	139.1
2½x2	0.250	1.80	1.162	25.5	37.6	46.5	53.9	60.3	74.0	85.5	95.6	104.7	113.1	120.9
4x4	0.313	4.76	5.40	17.3	30.4	40.1	47.8	54.3	67.7	78.7	88.2	96.8	104.7	112.0
5x5	0.313	6.49	9.58	14.3	26.6	36.5	44.6	51.4	65.3	76.4	86.0	94.6	102.4	109.6
6x4	0.230	4.16	7.25	18.2	35.2	50.3	63.5	75.1	98.6	117.3	133.2	147.1	159.8	171.4
6x6	0.240	5.40	10.06	12.0	23.6	34.6	44.9	54.3	74.7	91.3	105.3	117.6	128.6	138.6
6x6	0.438	9.18	15.87	11.9	22.7	31.9	39.7	46.3	59.7	70.4	79.5	87.6	94.9	101.7
8x5	0.230	5.90	14.18	14.0	27.7	40.6	52.8	64.0	88.3	108.2	125.1	139.9	153.1	165.1
8x7	0.245	8.32	21.04	11.0	21.7	31.8	41.4	50.2	69.4	85.2	98.6	110.3	120.7	130.2
8x8	0.288	10.72	27.41	8.8	17.5	25.8	33.6	40.0	57.3	70.9	82.5	92.7	101.8	110.0
8x8	0.500	12.99	30.33	9.3	18.3	26.6	34.2	41.1	55.6	67.2	77.0	85.6	93.3	100.4
10x5¾	0.240	7.30	21.56	12.9	25.6	37.8	49.5	60.6	85.3	106.1	124.1	139.8	153.8	166.5

TABLE 18d

Values of Equivalent Slenderness Ratio for Beams

ARMY-NAVY SERIES CHANNELS



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

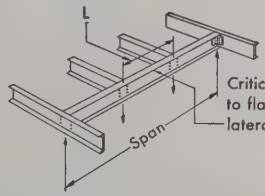
r_{b1} = equivalent radius of gyration, in., defined on page 118

Army-Navy Series Channels				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Depth, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.^{3}	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
2	0.125	0.551	0.270	44.9	70.2	88.1	102.7	115.3	141.8	164.0	183.5	201.1	217.2	232.3
2	0.188	1.464	0.828	21.0	35.4	45.8	54.0	61.0	75.6	87.6	98.2	107.6	116.3	124 4
2½	0.125	0.625	0.369	47.4	76.9	97.6	114.3	128.7	158.6	183.6	205.5	225.3	243.4	260.3
2½	0.156	0.901	0.569	35.3	58.2	74.3	87.3	98.4	121.5	140.7	157.6	172.7	186.7	199.6
3	0.156	0.993	0.732	36.3	61.5	79.6	94.0	106.3	131.6	152.6	171.0	187.5	202.7	216.7
3	0.188	1.354	1.036	29.0	49.6	64.4	76.2	86.2	106.9	124.0	139.0	152.4	164.7	176.2
4	0.188	1.575	1.540	30.0	53.6	71.4	85.7	97.7	122.3	142.3	159.7	175.3	189.6	202.8
4	0.250	2.205	2.156	26.0	45.2	59.2	70.4	79.8	99.3	115.3	129.2	141.8	153.3	163.9
5	0.188	1.810	2.107	30.7	56.4	76.8	93.3	107.2	135.4	158.2	177.8	195.4	211.5	226.3
5	0.250	2.499	2.954	26.7	48.0	64.1	77.1	88.0	110.2	128.3	144.0	158.1	171.0	183.0
6	0.188	2.128	3.002	27.3	51.9	72.8	90.4	105.5	135.9	160.2	180.9	199.2	216.0	231.4
6	0.250	2.940	4.179	24.3	45.3	62.5	76.5	88.4	112.4	131.7	148.3	163.0	176.5	189.0
7	0.188	3.611	7.148	18.1	35.7	52.2	67.5	81.4	111.3	135.6	156.1	174.1	190.1	204.8

TABLE 18e

Values of Equivalent Slenderness Ratio for Beams

ARMY-NAVY SERIES WIDE-FLANGE SECTIONS



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

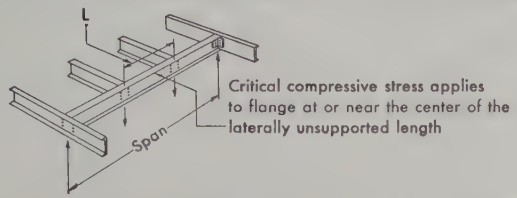
r_{b1} = equivalent radius of gyration, in., defined on page 118

Army-Navy Series Wide-Flange Sections				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Nominal Depth and Width, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.^{3}	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
2½x2	0.125	0.928	0.665	35.3	61.2	80.1	95.1	107.8	134.0	155.6	174.4	191.3	206.8	221.2
3x2	0.125	1.001	0.841	36.8	65.3	86.6	103.6	118.0	147.4	171.4	192.3	211.0	228.2	244.1
4x2	0.125	1.139	1.212	38.7	70.8	96.1	116.4	133.6	168.4	196.5	220.9	242.7	262.6	281.0
4x3	0.156	1.788	2.068	25.0	47.3	66.1	81.8	95.1	122.1	143.6	162.0	178.4	193.3	207.1
4x3½	0.250	3.060	3.484	20.5	37.6	51.1	62.0	71.1	89.7	104.7	117.7	129.3	139.9	149.8
4x4½	0.188	2.867	3.545	16.1	31.1	44.3	55.8	65.7	86.0	102.2	115.8	127.9	138.9	148.9
5x5	0.312	5.366	7.873	14.2	27 1	38.2	47.6	55.6	71.9	84.9	96.0	105.8	114.7	123.0

TABLE
18f

Values of Equivalent Slenderness Ratio for Beams

SPECIAL CHANNELS



$$\text{Equivalent slenderness ratio} = \frac{KL}{r_{b1}}$$

L = laterally unsupported length of beam, in.

K = factor representing end conditions of laterally unsupported length, same as for columns

r_{b1} = equivalent radius of gyration, in., defined on page 118

Special Channels				Equivalent Slenderness Ratio, KL/r_{b1}, for Various Values of Effective Unsupported Length										
Depth, In.	Thickness, In.	Weight, Lb/Ft	Section Modulus, In.^{3}	KL=20 In.	KL=40 In.	KL=60 In.	KL=80 In.	KL=100 In.	KL=150 In.	KL=200 In.	KL=250 In.	KL=300 In.	KL=350 In.	KL=400 In.
2	0.170	1.22	0.621	28.6	41.9	51.7	59.9	67.0	82.2	94.9	106.1	116.3	125.6	134.3
2½	0.250	1.24	0.703	34.8	51.4	63.6	73.7	82.5	101.2	116.9	130.8	143.3	154.8	165.5
3	0.250	2.24	1.74	24.6	38.8	48.8	56.9	63.9	78.6	90.9	101.7	111.5	120.4	128.8
3	0.375	2.70	1.92	25.0	35.8	43.1	50.7	56.7	69.5	80.2	89.7	98.3	106.1	113.1
4	0.318	3.32	3.42	17.8	27.1	33.7	39.2	43.9	54.0	62.4	69.8	76.4	82.6	88.3
5	0.188	3.10	4.48	20.1	34.7	45.3	53.8	61.0	75.8	87.9	98.6	108.1	116.9	125.0
5	0.438	5.82	7.25	18.2	30.0	38.3	45.0	50.7	62.7	72.6	81.3	89.1	96.3	102.9
6	0.500	5.77	8.02	18.3	32.4	42.9	51.3	58.4	72.9	84.7	95.0	104.3	112.8	120.6
6	0.375	5.93	9.41	16.3	29.9	40.7	49.4	56.8	71.7	83.7	94.1	103.4	111.9	119.7
8	0.380	6.59	13.54	19.5	36.1	49.5	60.4	69.7	88.4	103.4	116.3	127.9	138.4	148.2
8	0.425	7.86	15.94	16.4	30.6	42.1	51.6	59.7	75.9	88.9	100.1	110.1	119.2	127.6
10	0.375	8.58	21.92	17.0	32.3	45.2	56.0	65.3	83.9	98.8	111.5	122.9	133.2	142.7
10	0.500	10.05	24.01	16.5	31.1	43.0	53.0	61.4	78.3	91.9	103.6	114.0	123.5	132.2

From formula (5a), page 118,

$$\frac{KL}{r_{b3}}=\frac{1}{\sqrt{1.28}}\left(\frac{KL}{r_{b1}}\right)=\frac{46.7}{\sqrt{1.28}}=41.3$$

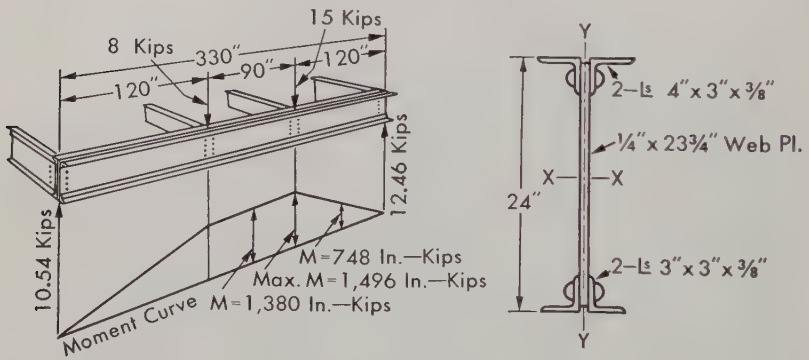
From Table 4b (extruded shapes), page 50, for thicknesses up to 0.499, C=50. Since KL/r_{b3} is less than C, use formula (2), page 112, to calculate buckling stress. Constants B and D are found in Table 4b, page 50.

$$f_C=61.4-0.410\times41.3=44.5 \text{ kips per sq in.}$$

The allowable stress is $\frac{44.5}{2.5}=17.8$ kips per sq in., and the allowable bending moment is 17.8 times the section modulus. From Table 43, page 224, the section modulus is 14.18. The allowable load is

$$P=\frac{17.8\times14.18}{70}=3.6 \text{ kips}$$

Example 10. Check the factor of safety against buckling for the 6061-T6 alloy plate girder shown in the sketch below. The girder is the same as that used in Example 2, page 97.



Section properties from Example 2:

$$I_x=1430 \text{ in.}^4$$

$\bar{y}$ (distance from neutral axis to compression flange) = 11.4 in.

Since this is an unsymmetrical I-section, the equivalent radius of gyration for buckling failure is found from formula (4b), page 118. For use in this formula, values of S_c, I_y, C_s, J and e are required.

$$S_c=\frac{I}{c}=\frac{1430}{11.4}=125 \text{ in.}^3$$

Calculation of I_y and J:

Section	Gross Area, A, Sq In.	For Axis Y			Torsion Constant, J In.⁴
		x In.	Ax^2 In.⁴	I_o In.⁴	
2 angles 4"×3"×3/8"	4.98	1.39	9.6	7.8	0.246
1 plate 1/4"×23 3/4"	5.94	0.00	0.0	0.0	0.124
2 angles 3"×3"×3/8"	4.20	1.00	4.2	3.4	0.210
			13.8	11.2	0.580

In calculating J above, the values for angles were taken from Table 40, pages 212 to 219, and the value for the plate was calculated from the formula for narrow rectangles in Table 15a, page 102:

$$J=\frac{bt^3}{3}=\tfrac{1}{3}\times 23.75\times(0.25)^3=0.124$$

$$I_y=13.8+11.2=25.0 \text{ in.}^4$$

Formulas for C_s and e are found in Table 15b, page 103.

$$C_s=\frac{d^2I_1I_2}{I_y}$$

$$I_1=9.6+7.8=17.4$$

$$I_2=4.2+3.4=7.6$$

$$C_s=\frac{(24)^2\times 17.4\times 7.6}{25.0}=3047 \text{ in.}^6$$

$$e=\frac{y_1I_1-y_2I_2}{I_y}$$

$$=\frac{11.4\times 17.4-12.6\times 7.6}{25.0}=4.1 \text{ in.}$$

For the 90-in. unsupported length, assuming K=0.8 (formula 4b):

$$r_{b_2}^2=\frac{25.0}{125}\left(4.1+\sqrt{(4.1)^2+\frac{1}{25.0}\left[3047+0.038\times 0.580(0.8\times 90)^2\right]}\right)$$

$$=3.21$$

$$r_{b_2}=1.79 \text{ in.}$$

$$\frac{KL}{r_{b_2}}=\frac{0.8\times 90}{1.79}=40$$

From Table 4c, page 52, C=63 for 6061-T6 shapes. Since $\frac{KL}{r_{b_2}}<63$, use column formula (2), page 112, to calculate buckling strength.

$$f_C=B-D\left(\frac{KL}{r_{b_2}}\right)=38.3-0.202\times 40=30.2 \text{ kips per sq in.}$$

The compressive stress at the center of the 90-in. unsupported span is

$$f=\frac{M}{S_c}=\frac{1380}{125}=11.0 \text{ kips per sq in.}$$

The factor of safety against buckling for the 90-in. span is

$$\frac{30.2}{11.0}=2.75$$

For the 120-in. unsupported length, assuming K=0.9:

$$r_{b_2}^2=\frac{25.0}{125}\left(4.1+\sqrt{(4.1)^2+\frac{1}{25.0}\left[3047+0.038\times 0.580(0.9\times 120)^2\right]}\right)$$

$$=3.26$$

$$r_{b_2}=1.81 \text{ in.}$$

$$\frac{KL}{r_{b_2}}=\frac{0.9\times 120}{1.81}=60$$

$$f_C=38.3-0.202\times 60=26.2 \text{ kips per sq in.}$$

The compressive stress at the center of the 120-in. unsupported span is

$$f = \frac{M}{S_c} = \frac{748}{125} = 6.0 \text{ kips per sq in.}$$

The factor of safety against buckling for the 120-in. span is

$$\frac{26.2}{6.0} = 4.4$$

Formulas (4a) and (4b), page 118, are based on the buckling strength of a beam subjected to a uniform bending moment. This is a good approximation of conditions frequently encountered in practice because beams are generally given lateral support at the points of load application so that the "laterally unsupported length," L, is the distance between load points. When the bending moment varies along the length, failure may be considered to occur when the stress at or near the center of the unsupported length reaches the buckling stress determined on the basis of these formulas. This latter approximation should be used with caution if the maximum bending moment exceeds the bending moment at the center of the unsupported length by more than 80 per cent.

Formulas (4a) and (4b), page 118, may also be applied where the beam is not supported laterally at the points of load application. The results will be conservative for all cases of this kind where the ends of the beam are simply supported and the loads are applied at or below the neutral axis of the beam. The formulas may be unconservative (that is, give an equivalent radius of gyration that is too large) when transverse (vertical) loads are applied at the top flange, but for usual design purposes the errors are not serious.

Formulas (5a) and (5b), pages 118 and 119, are based on somewhat conservative approximations for the case of loads applied at the neutral axis of a cantilever beam.[1] For a cantilever beam, failure may be expected when the stress in the compression flange at the supported end reaches the buckling stress. Formulas are given for two different loading conditions because the buckling strength of a cantilever beam is much more sensitive to the type of loading than is the strength of a simple beam.

When formulas (4a), (5a) or (5b), pages 118 and 119, are applied to channel members, any loads at points that are not supported against rotation should be applied so that their lines of action pass through the shear center of the section (see page 104 and Table 15b, page 103).

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[1] See, for example, S. Timoshenko, *Theory of Elastic Stability*, Chapter V, McGraw-Hill Book Co., Inc., New York, 1936.

Double-web box girders, because of their tube-like cross section, are very much stiffer in torsion than single-web girders of comparable size. For the depth-width ratios ordinarily encountered, double-web box girders are so stiff in torsion that lateral buckling failures need not be considered in design. The allowable stress on the compression flange of such members is usually restricted by the possibility of local buckling of the compression cover plate (see pages 130 to 137).

Beam-Columns

The amount of axial compressive force that a member will carry is reduced by the presence of a transverse bending moment. Similarly, the ability to resist transverse bending loads is impaired by the presence of an axial compressive load.

Combinations of axial compressive stress and transverse bending stress that will cause failure may be found from the formula

$$\frac{f_c}{f_C} + \frac{f_b}{f_B(1-f_c/f_{CE})} = 1 \qquad (6)$$

where f_c = average compressive stress on cross section of member produced by axial compressive force, kips per sq in.

f_C = critical stress for member under axial compressive load only, kips per sq in. (see pages 110 to 118)

f_b = maximum bending stress $\left(\frac{M_{bc}}{I} \text{ for compression side}\right)$ on extreme fiber at or near center of unsupported length, caused by transverse bending moment, kips per sq in.

f_B = critical bending stress $\left(\frac{M_{Bc}}{I} \text{ for compression side}\right)$ for member under bending only, kips per sq in. (see pages 96, 118 and 158)

$$f_{CE} = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2}$$

$\frac{KL}{r}$ = effective slenderness ratio for member considered as a column tending to fail in the plane of the applied bending moment.

The values of f_C and f_B to be used in this formula are the least values of these quantities for the member, regardless of the direction or the type of failure (over-all buckling, local buckling or excessive yielding).

If the loads on the member are such that the quantities on the left side of formula (6), above, total less than unity, then failure will not occur.

It should be noted that f_c and f_b in the formula are not the working stresses but rather the stresses which in combination will cause failure of the member. If the formula is used to check whether a member will carry certain working loads with a prescribed factor of safety, then the value of f_c which should be substituted in formula (6), page 129, is equal to the factor of safety times the axial stress caused by the working load, and f_b is equal to the factor of safety times the bending stress caused by the working loads. If, then, the sum on the left side of formula (6) is equal to, or less than, unity, the factor of safety is equal to, or greater than, the prescribed value.

Example 11. Determine whether the member in Example 9, page 119, can carry a load P of 2 kips and at the same time safely support an axial compressive load of 6 kips. Use a factor of safety of 2.5.

From Example 9, the critical bending stress f_B when no axial load is present is 44.5 kips per sq in.

From Table 43, page 224, the least radius of gyration for column failure is 1.22. For a cantilever column, K=2.

$$\frac{KL}{r}=\frac{2\times 70}{1.22}=114.8$$

From formula (1), page 111, the column strength when no transverse load is present is

$$f_C=\frac{102{,}000}{\left(\frac{KL}{r}\right)^2}=\frac{102{,}000}{(114.8)^2}=7.7 \text{ kips per sq in.}$$

From Table 43, the radius of gyration for the member as a column tending to fail in the plane of the applied bending moment is 3.36. Therefore,

$$f_{CE}=\frac{102{,}000}{\left(\frac{KL}{r}\right)^2}=\frac{102{,}000}{(2\times 70/3.36)^2}=58.8 \text{ kips per sq in.}$$

The stress f_c equals the axial compressive stress times the required factor of safety. The cross-sectional area of the member is 5.02 sq in. (Table 43, page 224).

$$f_c=\frac{2.5}{5.02}\times 6.0=3.0 \text{ kips per sq in.}$$

The stress f_b equals the bending stress multiplied by the required factor of safety.

$$f_b=\frac{2.5M}{S}=\frac{2.5\times 2\times 70}{14.18}=24.7 \text{ kips per sq in.}$$

The sum on the left side of formula (6), page 129, is

$$\frac{f_c}{f_C}+\frac{f_b}{f_B(1-f_c/f_{CE})}=\frac{3.0}{7.7}+\frac{24.7}{44.5(1-3.0/58.8)}=0.98$$

Since the above sum is slightly less than unity, the factor of safety against collapse of the member under the given loads is slightly greater than 2.5.

Flat Plates in Edge Compression

A flat plate, loaded in edge compression and supported along one or both of the unloaded edges, may buckle in the form of local waves or

wrinkles. If the plate is part of a column or beam, this local buckling may occur at stresses considerably below the critical stress for the member as a whole.

Local buckling of plates in edge compression may be treated conveniently as local column failure, using an equivalent slenderness ratio for plates in the formulas for column buckling (formulas [1] and [2], pages 111 and 112). The equivalent slenderness ratio for relatively short, wide plates in compression is

$$\frac{KL}{r} = k\frac{L}{t} \tag{7a}$$

where $\frac{KL}{r}$ = equivalent slenderness ratio for plate,

L = unsupported length of plate, in.,

t = thickness of plate, in.,

k = a factor depending upon the ratio of length to width of the plate and the conditions of support.

Values of the factor k for various proportions of panel and conditions of support are listed in the first section of Table 19a, page 132.

When the length is greater than the width, it is more convenient to express the equivalent slenderness ratio of a flat plate in edge compression as

$$\frac{KL}{r} = k'\frac{b}{t} \tag{7b}$$

where b = unsupported width of plate, in.,

k′ = a factor depending upon the ratio of length to width of the plate and the conditions of support.

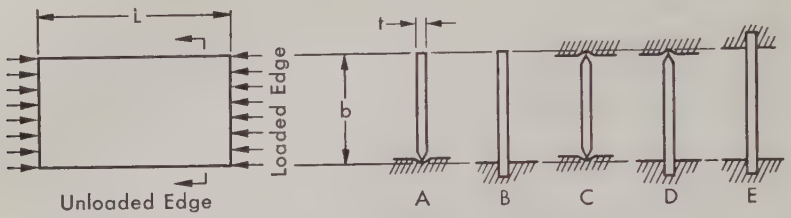
Values of k′ for various proportions of panel and conditions of support are listed in the second section of Table 19a.

For plates whose length is greater than about five times the width, the factor k′ is practically independent of length and of the conditions of support at the loaded edges. So for long plates, the equivalent slenderness ratio depends only on the ratio b/t. Table 19b, page 133, gives equivalent slenderness ratios for long plates having various ratios of width to thickness, b/t. For short plates, the equivalent slenderness ratio should be calculated from Table 19a, page 132, if the designer wishes to take advantage of the increase in buckling stress accompanying the decreased length.

If the flat plate is one leg of an angle or tee section whose other legs are of similar proportions, the unloaded edges of the plate should be regarded as free on one side and simply supported on the other. When an unloaded edge of a plate is built into elements that

TABLE 19a

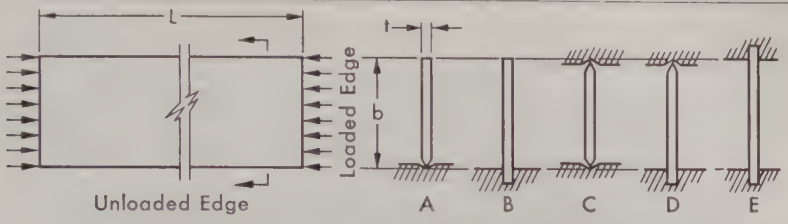
Values of Factors k and k′ in Formulas for Equivalent Slenderness Ratio, $\frac{KL}{r}$, of Flat Plates in Edge Compression



$\frac{L}{b}$	CASE A One Unloaded Edge Simply Supported, Other Unloaded Edge Free		CASE B One Unloaded Edge Fixed, Other Unloaded Edge Free		CASE C Both Unloaded Edges Simply Supported		CASE D One Unloaded Edge Fixed, Other Unloaded Edge Simply Supported		CASE E Both Unloaded Edges Fixed	
	Loaded Edges Simply Supported	Loaded Edges Fixed	Loaded Edges Simply Supported	Loaded Edges Fixed	Loaded Edges Simply Supported	Loaded Edges Fixed	Loaded Edges Simply Supported	Loaded Edges Fixed	Loaded Edges Simply Supported	Loaded Edges Fixed
Values of k, where $\frac{KL}{r} = k\frac{L}{t}$										
0.0	3.27	1.63	3.27	1.63	3.27	1.63	3.27	1.63	3.27	1.63
0.2	3.24	1.63	3.24	1.63	3.15	1.62	....	....	....	....
0.4	3.17	1.62	3.17	1.62	2.81	1.57	....	....	....	....
0.6	3.05	1.60	3.04	1.59	2.40	1.49	2.24	....	2.05	....
0.8	2.91	1.58	2.77	1.55	1.99	1.38	1.75	1.27	1.54	1.18
1.0	2.75	1.56	2.55	1.51	1.63	1.26	1.40	1.12	1.24	1.02
Values of k′, where $\frac{KL}{r} = k'\frac{b}{t}$										
1.0	2.75	1.56	2.55	1.51	1.63	1.26	1.40	1.12	1.24	1.02
1.2	3.11	1.83	2.77	1.73	1.63	1.35	1.40	1.19	1.24	1.07
1.4	3.41	2.09	2.88	1.92	1.63	1.40	1.40	1.24	1.24	1.11
1.6	3.65	2.33	2.89	2.08	1.63	1.44	1.40	1.27	1.24	1.14
1.8	3.86	2.55	2.89	2.22	1.63	1.46	1.40	1.29	1.24	1.16
2.0	4.03	2.76	2.89	2.33	1.63	1.49	1.40	1.31	1.24	1.17
2.5	4.33	3.19	2.89	2.58	1.63	1.54	1.40	1.34	1.24	1.19
3.0	4.53	3.54	2.89	2.74	1.63	1.57	1.40	1.36	1.24	1.21
4.0	4.77	4.03	2.89	2.88	1.63	1.60	1.40	1.39	1.24	1.23
5.0	4.88	4.34	2.89	2.89	1.63	1.61	1.40	1.40	1.24	1.24
	5.13	5.13	2.89	2.89	1.63	1.63	1.40	1.40	1.24	1.24

TABLE 19b

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Long Flat Plates in Edge Compression



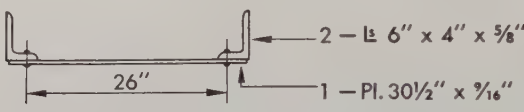
$$\frac{b}{t} = \frac{\text{unsupported width of plate}}{\text{thickness of plate}}$$

$\frac{b}{t}$	$\frac{KL}{r}$				
	CASE A One Unloaded Edge Simply Supported, Other Unloaded Edge Free	CASE B One Unloaded Edge Fixed, Other Unloaded Edge Free	CASE C Both Unloaded Edges Simply Supported	CASE D One Unloaded Edge Fixed, Other Unloaded Edge Simply Supported	CASE E Both Unloaded Edges Fixed
	$\frac{KL}{r} = 5.13\frac{b}{t}$	$\frac{KL}{r} = 2.89\frac{b}{t}$	$\frac{KL}{r} = 1.63\frac{b}{t}$	$\frac{KL}{r} = 1.40\frac{b}{t}$	$\frac{KL}{r} = 1.24\frac{b}{t}$
2	10.3	5.8	3.3	2.8	2.5
4	20.5	11.6	6.5	5.6	5.0
6	30.8	17.3	9.8	8.4	7.4
8	41.0	23.1	13.0	11.2	9.9
10	51.3	28.9	16.3	14.0	12.4
12	61.6	34.7	19.6	16.8	14.9
14	71.8	40.5	22.8	19.6	17.4
16	82.1	46.2	26.1	22.4	19.8
18	92.3	52.0	29.3	25.2	22.3
20	102.6	57.8	32.6	28.0	24.8
22	112.9	63.6	35.9	30.8	27.3
24	123.1	69.4	39.1	33.6	29.8
26	133.4	75.1	42.4	36.4	32.2
28	143.6	80.9	45.6	39.2	34.7
30	153.9	86.7	48.9	42.0	37.2
32	164.2	92.5	52.2	44.8	39.7
34	174.4	98.3	55.4	47.6	42.2
36	184.7	104.0	48.7	50.4	44.6
38	194.9	109.8	61.9	53.2	47.1
40	205.2	115.6	65.2	56.0	49.6
45	230.9	130.1	73.4	63.0	55.8
50	256.5	144.5	81.5	70.0	62.0
55	282.2	159.0	89.7	77.0	68.2
60	307.8	173.4	97.8	84.0	74.4
65	333.5	187.9	106.0	91.0	80.6
70	359.1	202.3	114.1	98.0	86.8
75	384.8	216.8	122.3	105.0	93.0
80	410.4	231.2	130.4	112.0	99.2
90	461.7	260.1	146.7	126.0	111.6
100	513.0	289.0	163.0	140.0	124.0

are capable of resisting rotation, the edge should be considered partially restrained, and a value of k or k′, intermediate between the values for the fixed and simply-supported conditions, should be chosen.

The effective slenderness ratio for short plates is considerably affected by the condition of restraint at the loaded edges. Generally, the edge condition will be between fixed and simply supported. It should be remembered that the fixed condition can be approached only if the plate is rigidly attached to a much stiffer structure.

Example 12. Calculate the edge compression stresses that will cause local buckling of the elements of the 6061-T6 section shown in the sketch, assuming that the length of the member is greater than five times the width of the plate and that the section as a whole is adequately supported against buckling as a column.



From Table 19a, page 132, the equivalent slenderness ratio for the plate will be between 1.63 b/t for both unloaded edges simply supported and 1.24 b/t for both unloaded edges fixed. Assume that the equivalent slenderness ratio is 1.5 b/t.

$$\frac{KL}{r} = 1.5 \times \frac{26}{9/16} = 69.3$$

From Table 4a, page 48, C=68 for 6061-T6 plate. Since KL/r > 68, formula (1), page 111, applies. The buckling stress for the plate is

$$f_C = \frac{102{,}000}{(69.3)^2} = 21.2 \text{ kips per sq in.}$$

From Table 19a, page 132, the equivalent slenderness ratio for the outstanding leg of the angle will be between 5.13 b/t for the attached edge simply supported and 2.89 b/t for the attached edge fixed. Assume that the equivalent slenderness ratio is 4 b/t.

$$\frac{KL}{r} = 4 \times \frac{(6 - 5/8)}{5/8} = 34.4$$

From Table 4c, page 52, C=63 for 6061-T6 standard structural shapes. Since KL/r < 63, formula (2), page 112, applies. The buckling stress for the outstanding leg of the angle is (constants B and D from Table 4c):

$$f_C = B - D\frac{KL}{r} = 38.3 - 0.202 \times 34.4 = 31.4 \text{ kips per sq in.}$$

The importance of buckling of flat plates depends upon the proportions of the member of which the flat plate is a part. When one or both unloaded edges are fastened to parts much stiffer than the plate itself, buckling of the flat plate is very likely to be of the less significant type because the plate can buckle without precipitating collapse of the member as a whole. On the other hand, when the plate

is one leg of an angle or T-section and is therefore a major portion of the total cross-sectional area, buckling of the flat plate is very likely to bring about collapse of the member as a whole. The factor of safety to be used against buckling of flat plates will depend upon which type of buckling is involved.

When a flat plate loaded in edge compression is fastened at one or both unloaded edges to parts stiffer than the plate itself, it will continue to carry some load after the local buckling stress has been exceeded. It is sometimes desirable to take advantage of this extra load-carrying capacity if appearance of the buckled plate is not an important factor. This can be done by the effective-area method described below.

After the local buckling stress has been exceeded, only a portion of the plate along the attached edge is considered effective in carrying load. The remainder of the plate is assumed to carry no load. The width of the portion of the plate that is considered to be effective after local buckling is called the "effective width." The sum of the portions of the plate areas considered effective plus the areas of other elements of the member that are not affected by local buckling is called the effective area of the member.

The effective area of a flat-plate element of a member under a given edge compression load may be approximated by the following steps:

(a) Compute the stress f_c on the flat plate, based on the gross area, without regard to local buckling, for the loading under consideration.

(b) Compute the stress f_1 which will cause local buckling of the flat plate. If f_1 is greater than f_c, local buckling is not a problem for the load under consideration and the entire area of the plate may be considered effective.

(c) If f_1 is less than f_c, then only a part of the plate's unsupported width should be included in computing its effective area. The part of the unsupported width of a flat plate that should be considered effective may be found from the formula

$$b_e = b\frac{f_1}{f_c} \tag{8}$$

where b_e = that part of the unsupported width considered effective for the loading under consideration, in.,

b = unsupported width, in.,

f_c = compressive stress on gross area from step (a), kips per sq in.

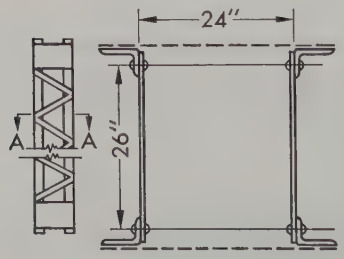
f_1 = the local buckling stress found in step (b) for the flat plate in question, kips per sq in.

When the effective areas of the plate elements of a column have been determined as outlined above, the average stress on the effective area may be found by simply dividing the axial load on the column by the total effective area.

In the case of a beam or girder, the stress on the effective area of the compression flange for the loading under consideration may be found by multiplying the stress on the gross section of the flange by the ratio of the gross area to the effective area. In computing both areas for a beam or girder, that part of the web should be included which is in the outermost one-sixth of the over-all depth of the beam or girder.

While the effective-width method outlined above is applicable to any given loading condition, it is ordinarily used only to determine whether a member has an adequate factor of safety against collapse in cases where a smaller factor of safety against local buckling of plate elements is used. Therefore, the loading that will generally be used in step "a" to establish the stress f_c is the ultimate load that the member must carry. The effective area is then established as outlined above and used to determine the effective stress developed in the part by the loading in question. If this stress is less than the column or beam-buckling stress for the member, the member will not fail at the assumed loading. In determining the buckling stress, it is sufficiently accurate for design purposes to use the radius of gyration (or equivalent radius of gyration in the case of a beam) based on the gross section.

Example 13. Determine whether the 6061-T6 alloy column shown in the sketch will carry a load of 600 kips with a factor of safety of 2.5. Assume that the effective slenderness ratio KL/r for the column is 40. The elements of the column section are the same as those used in Example 12, page 134.



Section A-A

	Area
4—L 6"x 4"x 5/8"	23.40
2—Pl. 30½"x 9/16"	34.31
	57.71 in.²

In order that the column may carry a load of 600 kips with a factor of safety of 2.5, the ultimate strength of the column must be at least $600 \times 2.5 = 1500$ kips. For this load the average stress f_c on the gross area is:

$$f_c = \frac{1500}{57.71} = 26.0 \text{ kips per sq in.}$$

From Example 12, the local buckling stress for the plates, $f_1 = 21.2$ kips per sq in. Compute the effective width of the plates between rivet lines at the 1500-kip load using formula (8), page 135.

$$b_e = b\frac{f_1}{f_c} = 26 \times \frac{21.2}{26.0} = 21.2 \text{ in.}$$

The total effective area is:

2 plates — $2 \times 9/16[21.2 + (30.5-26)]$	28.9
4 angles —	23.4
	52.3 in.^{2}

The average compressive stress on the effective area is 1500/52.3 = 28.7 kips per sq in. The buckling stress for the column as a whole is calculated from formula (2), page 112, using constants B and D for 6061-T6 plate from Table 4a, page 48:

$$f_C = B - D\frac{KL}{r} = 39.9 - 0.263 \times 40 = 29.4 \text{ kips per sq in.}$$

Since the average stress on the effective area is less than 29.4 kips per sq in., the factor of safety is greater than 2.5.

Flat Plates in Shear

Buckling of plates under shearing forces can also be treated by the equivalent-slenderness-ratio method, provided that the proper equations are used which relate the equivalent slenderness ratio and the dimensions of the panel.

For relatively thin plates, the shear buckling stress is

$$f_S = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2} \tag{9}$$

where f_S = shear stress to cause buckling, kips per sq in.,
$\frac{KL}{r}$ = equivalent slenderness ratio for shear buckling.

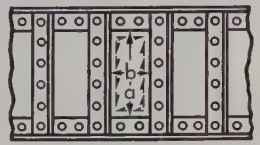
Formula (9) is of the same form as formula (1), page 111, for compressive buckling. For relatively thick plates, when the equivalent slenderness ratio is less than the constant C_1,

$$f_S = B_1 - D_1\frac{KL}{r} \tag{10}$$

where B_1, D_1 and C_1 depend upon the properties of the material. Values of these constants corresponding to minimum mechanical properties of the various aluminum alloys and products are listed with the mechanical properties in Table 4, pages 42 to 66. Formula (10) is similar to formula (2), page 112, for compressive buckling,

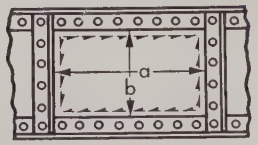
TABLE 20

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Flat Plates in Shear



$\frac{b}{t} = \frac{\text{short dimension of panel}}{\text{thickness of plate}}$

$\frac{b}{a} = \frac{\text{short dimension of panel}}{\text{long dimension of panel}}$



$\frac{b}{t}$	$\frac{b}{a}$=0		$\frac{b}{a}$=0.2		$\frac{b}{a}$=0.4		$\frac{b}{a}$=0.5		$\frac{b}{a}$=0.6		$\frac{b}{a}$=0.7		$\frac{b}{a}$=0.8		$\frac{b}{a}$=0.9		$\frac{b}{a}$=1.0	
	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed
20	28.3	21.9	27.9	21.6	26.7	20.9	26.0	20.4	25.1	19.8	24.2	19.2	23.3	18.5	22.3	17.8	21.4	17.2
22	31.1	24.1	30.7	23.8	29.4	23.0	28.6	22.4	27.6	21.8	26.6	21.1	25.6	20.3	24.5	19.6	23.5	18.9
24	33.9	26.3	33.4	26.0	32.1	25.1	31.1	24.4	30.1	23.7	29.0	23.0	27.9	22.2	26.8	21.4	25.7	20.6
26	36.8	28.5	36.2	28.1	34.7	27.1	33.7	26.5	32.6	25.7	31.4	24.9	30.2	24.0	29.0	23.2	27.8	22.3
28	39.6	30.7	39.0	30.3	37.4	29.2	36.3	28.5	35.1	27.7	33.9	26.8	32.6	25.9	31.2	25.0	29.9	24.0
30	42.4	32.9	41.8	32.5	40.1	31.3	38.9	30.5	37.6	29.7	36.3	28.7	34.9	27.7	33.5	26.7	32.1	25.7
32	45.3	35.1	44.6	34.6	42.8	33.4	41.5	32.6	40.2	31.6	38.7	30.6	37.2	29.6	35.7	28.5	34.2	27.5
34	48.1	37.2	47.4	36.8	45.4	35.5	44.1	34.6	42.7	33.6	41.1	32.6	39.5	31.4	37.9	30.3	36.3	29.2
36	50.9	39.4	50.2	38.9	48.1	37.6	46.7	36.7	45.2	35.6	43.5	34.5	41.9	33.3	40.2	32.1	38.5	30.9
38	53.7	41.6	52.9	41.1	50.8	39.7	49.3	38.7	47.7	37.6	46.0	36.4	44.2	35.1	42.4	33.9	40.6	32.6
40	56.6	43.8	55.7	43.3	53.5	41.8	51.9	40.7	50.2	39.6	48.4	38.3	46.5	37.0	44.6	35.7	42.8	34.3
42	59.4	46.0	58.5	45.4	56.1	43.9	54.5	42.8	52.7	41.5	50.8	40.2	48.8	38.8	46.8	37.4	44.9	36.0
44	62.2	48.2	61.3	47.6	58.8	45.9	57.1	44.8	55.2	43.5	53.2	42.1	51.2	40.7	49.1	39.2	47.0	37.8
46	65.1	50.4	64.1	49.8	61.5	48.0	59.7	46.8	57.7	45.5	55.6	44.0	53.5	42.5	51.3	41.0	49.2	39.5
48	67.9	52.6	66.9	51.9	64.1	50.1	62.3	48.9	60.2	47.5	58.0	46.0	55.8	44.4	53.5	42.8	51.3	41.2

$\frac{b}{t}$	$\frac{b}{a}=0$		$\frac{b}{a}=0.2$		$\frac{b}{a}=0.4$		$\frac{b}{a}=0.5$		$\frac{b}{a}=0.6$		$\frac{b}{a}=0.7$		$\frac{b}{a}=0.8$		$\frac{b}{a}=0.9$		$\frac{b}{a}=1.0$	
	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed	Edges Simply Supported	Edges Fixed
50	70.7	54.8	69.7	54.1	66 8	52.2	64.9	50.9	62.7	49.5	60.5	47.9	58.1	46.2	55.8	44.6	53.5	42.9
52	73.5	57.0	72.5	56.3	69.5	54.3	67.5	52.9	65.3	51.4	62.9	49.8	60.5	48.1	58.0	46.3	55.6	44.6
54	76.4	59.2	75.2	58.4	72 2	56.4	70.1	55.0	67.8	53.4	65.3	51.7	62.8	49.9	60.2	48.1	57.7	46.3
56	79.2	61.3	78.0	60.6	74 8	58.5	72.7	57.0	70.3	55.4	67.7	53.6	65.1	51.8	62.5	49.9	59.9	48.0
58	82.0	63.5	80.8	62.8	77.5	60.6	75.3	59.1	72.8	57.4	70.1	55.5	67.4	53.6	64.7	51.7	62.0	49.8
60	84.9	65.7	83.6	64.9	80.2	62.6	77.9	61.1	75.3	59.3	72.6	57.5	69.8	55.5	66.9	53.5	64.1	51.5
62	87.7	67.9	86.4	67.1	82.9	64.7	80.5	63.1	77.8	61.3	75.0	59.4	72.1	57.3	69.2	55.3	66.3	53.2
64	90.5	70.1	89.2	69.2	85.5	66.8	83.1	65.2	80.3	63.3	77.4	61.3	74.4	59.2	71.4	57.0	68.4	54.9
66	93.3	72.3	92.0	71.4	88.2	68.9	85.7	67.2	82.8	65.3	79.8	63.2	76.7	61.0	73.6	58.8	70.6	56.6
68	96.2	74.5	94.8	73.6	90.9	71.0	88.3	69.2	85.3	67.3	82.2	65.1	79.1	62.9	75.8	60.6	72.7	58.3
70	99.0	76.7	97.5	75.7	93.5	73.1	90.8	71.3	87.8	69.2	84.7	67.0	81.4	64.7	78.1	62.4	74.8	60.1
75	106.1	82.2	104.5	81.1	100.2	78.3	97.3	76.4	94.1	74.2	90.7	71.8	87.2	69.4	83.7	66.8	80.2	64.4
80	113.1	87.6	111.5	86.6	106.9	83.5	103.8	81.5	100.1	79.1	96.7	76.6	93.0	74.0	89.2	71.3	85.5	68.6
85	120.2	93.1	118.4	92.0	113.6	88.7	110.3	86.5	106.7	84.1	102.8	81.4	98.8	78.6	94.8	75.8	90.9	72.9
90	127.3	98.6	125.4	97.4	120.3	94.0	116.8	91.6	112.9	89.0	108.8	86.2	104.6	83.2	100.4	80.2	96.2	77.2
100	141.4	109.5	139.3	108.2	133.6	104.4	129.8	101.8	125.5	98.9	120.9	95.8	116.3	92.5	111.5	89.1	106.9	85.8
110	155.6	120.5	153 3	119.0	147.0	114.9	142.8	112.0	138.0	108.8	133.0	105.3	127.9	101.7	122.7	98.0	117.6	94.4
120	169.7	131.4	167.2	129.8	160.4	125.3	155.7	122.2	150.6	118.7	145.1	114.9	139.5	111.0	133.8	107.0	128.3	103.0
130	183.8	142.4	181.1	140.6	173.7	135.7	168.7	132.4	163.1	128.6	157.2	124.5	151.1	120.2	145.0	115.9	139.0	111.5
140	198.0	153.4	195.1	151.5	187.1	146.2	181.7	142.5	175.7	138.5	169.3	134.1	162.8	129.5	156.2	124.8	149.7	120.1
150	212.1	164.3	209.0	162.3	200.4	156.6	194.7	152.7	188.2	148.4	181.4	143.6	174.4	138.7	167.3	133.7	160.4	128.7
175	247.5	191.7	243.8	189.3	233.9	182.7	227.1	178.2	219.6	173.1	211.6	167.6	203.4	161.8	195.2	156.0	187.1	150.2
200	282.8	219.1	278.7	216.4	267.3	208.8	259.6	203.6	251.0	197.8	241.9	191.5	232.5	185.0	223.1	178.3	213.8	171.6
250	353.6	273.9	348.4	270.5	334.1	261.0	324.5	254.6	313.7	247.3	302.3	239.4	290.6	231.2	278.9	222.8	267.3	214.5
300	424.3	328.6	418.0	324.6	400.9	313.2	389.3	305.5	376.5	296.7	362.8	287.3	348.8	277.4	334.6	267.4	320.7	257.4

but the constants in the formula have different values because of the differences in stress-strain characteristics in shear and in compression.

Care should be taken to apply the constants B_1, D_1 and C_1 only to buckling under shear stress. The constants B, D and C, also listed in Table 4, apply to compressive buckling.

When a flat rectangular panel is simply supported on all four edges, the equivalent slenderness ratio, KL/r, to be substituted in formula (9) or (10) to determine the shear buckling stress is

$$\frac{KL}{r} = \frac{b}{t}\sqrt{\frac{2}{1+0.75\left(\frac{b}{a}\right)^2}} \qquad (11)$$

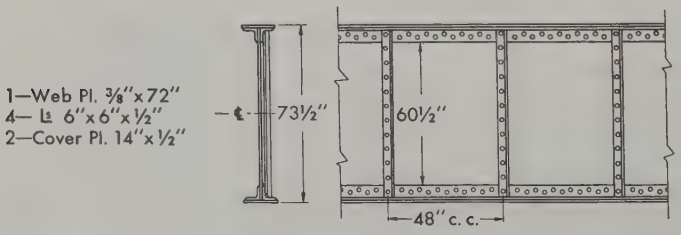
where b = unsupported width of plate (shorter panel dimension), in.,
t = thickness of plate, in.,
a = unsupported length of plate (larger panel dimension), in.

If the panel is fixed at all four edges, the equivalent slenderness ratio is

$$\frac{KL}{r} = \frac{b}{t}\sqrt{\frac{1.2}{1+0.63\left(\frac{b}{a}\right)^2}} \qquad (12)$$

The equivalent slenderness ratio of most practical panels will be between the values given by formulas (11) and (12). Values of equivalent slenderness ratio for shear buckling of flat plate panels of various proportions are listed in Table 20, pages 138 and 139.

Example 14. Calculate the shear force that will cause web buckling in the 6061-T6 alloy plate girder shown.



Equivalent slenderness ratio for a web panel lies between the values for panels simply supported and panels fixed (formulas [11] and [12], above):

$$\frac{KL}{r} = \frac{b}{t}\sqrt{\frac{2}{1+0.75(b/a)^2}} = \frac{b}{t}\sqrt{\frac{2}{1+0.75\left(\frac{48}{60.5}\right)^2}} = 1.17\frac{b}{t}$$

$$\frac{KL}{r}=\frac{b}{t}\sqrt{\frac{1.2}{1+0.63(b,a)^2}}=\frac{b}{t}\sqrt{\frac{1.2}{1+0.63\left(\frac{48}{60.5}\right)^2}}=0.93\frac{b}{t}$$

Assume $\frac{KL}{r}=1.05\frac{b}{t}=1.05\times\frac{48}{0.375}=134.$

From Table 4a, page 48, $C_1=88$. Since $\frac{KL}{r}>88$, formula (9) applies (see page 137); shear buckling stress is

$$f_S=\frac{102{,}000}{\left(\frac{KL}{r}\right)^2}=\frac{102{,}000}{(134)^2}=5.68 \text{ kips per sq in.}$$

Shear force on web to cause web buckling $=5.68\times(72\times0.375)=153$ kips.

Shear buckling of rectangular panels or flat plates rarely causes complete failure. Even after the panel has buckled it will continue to carry shear forces by diagonal tension or "tension-field" action. The ultimate strength of the panel will then be limited by the tensile strength of the plate, by the strength of the connections between the plate and the edge stiffeners or by the strength of the stiffener members themselves.

The principal reason for guarding against shear buckling of flat plate panels is to avoid the unsightly appearance of a wrinkled sheet at operating loads. Such buckling can be avoided by keeping the shear stress at operating loads below the critical value calculated as shown in the foregoing paragraphs. Since no question of collapse of the structure is involved, the factor of safety used may be relatively small.

If it is desired to calculate the reserve strength of a rectangular flat panel after shear buckling, further assistance can be found in references on diagonal tension webs.[1]

Flat Plates in Bending in the Plane of the Plate

The stress in the web of a beam or girder subjected to bending varies from tension at one flange to compression at the other. Thin webs may buckle under the influence of the compression stresses in a manner similar to the buckling of flat plates in edge compression. To determine the critical stress, an equivalent slenderness ratio may be used with the column formulas for the material in question (see formulas [1] and [2], pages 111 and 112, and Table 4, pages 42 to 66).

If the beam flanges furnish simple support to the unloaded edges of a web in bending, the equivalent slenderness ratio of the web is

---

[1] For example, P. Kuhn, J. P. Peterson and L. R. Levin, "A Summary of Diagonal Tension—Part I, Methods of Analysis," *Technical Note* 2661, National Advisory Committee for Aeronautics, 1952.

$$\frac{KL}{r} = 0.67\frac{h}{t} \tag{13}$$

where h = height of web between flanges, in.
t = thickness of web, in.

If the beam flanges fix the edges of the web against rotation, then

$$\frac{KL}{r} = 0.52\frac{h}{t} \tag{14}$$

The equivalent slenderness ratio for an actual web will lie between the values given by the formulas above.

The critical stress found by substituting the equivalent slenderness ratio in the proper column formula applies to the compression edge of the clear height of the web, adjacent to the compression flange. Table 21, page 144, gives values of equivalent slenderness ratio for buckling of aluminum alloy flat plates under bending in the plane of the plate.

It is customary to apply a relatively low factor of safety to the buckling strength of webs under bending in the plane of the web because the web's contribution to the bending strength of the beam is relatively minor and hence can be lost completely without precipitating collapse of the beam.

Example 15. Determine the bending moment on the girder in Example 14, page 140, that will cause buckling of the web.

Equivalent slenderness ratio for a web panel subjected to bending stress in the plane of the web (formulas [13] and [14], above) lies between

$$\frac{KL}{r} = 0.67\frac{h}{t} \text{ and } \frac{KL}{r} = 0.52\frac{h}{t} \text{ (h = clear height of web).}$$

Assume $\frac{KL}{r} = 0.6\frac{h}{t} = 0.6 \times \frac{60.5}{0.375} = 96.8$

From Table 4a, page 48, C = 68; since $\frac{KL}{r} > 68$, formula (1), page 111, applies. Buckling stress is

$$f_B = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2} = \frac{102{,}000}{(96.8)^2} = 10.9 \text{ kips per sq in.}$$

Moment of inertia of beam about center line,

Web plate, $\frac{1}{12}(0.375)(72)^3$	= 11,660
Flange plates, $2 \times 7.0\,(36.5)^2$	= 18,650
Angles, $4[19.38 + 5.74\,(34.59)^2]$	= 27,550
	I = 57,860 in.^{4}

Distance c from neutral axis to toe of compression flange is 30.25 in.

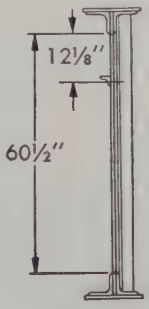
Bending moment to cause web buckling is $\frac{f_B I}{c} = \frac{10.9 \times 57{,}860}{30.25} = 20{,}800$ in.-kips.

The resistance of a web to the buckling caused by bending in its plane may be increased by means of a stiffener parallel to the compression flange as shown in Table 21, page 144. An economical location for such a stiffener is at a distance from the inside edge of the compression flange equal to 0.4 times the clear distance from the compression flange to the neutral axis. In this case, the equivalent slenderness ratio for the web in bending (assuming simply supported edges) is

$$\frac{KL}{r} = 0.29\frac{h}{t} \qquad (15)$$

As in the case where no horizontal stiffener is present, the equivalent slenderness ratio used with the proper column formula determines the critical value of the compressive stress in the web adjacent to the compression flange.

Example 16. If a horizontal stiffener is added to the girder shown in Example 14, page 140, determine the bending moment that will cause buckling of the web.



Location of horizontal stiffener (distance from toe of compression flange, see above):

$$0.4 \times 30\tfrac{1}{4} = 12\tfrac{1}{8} \text{ in.}$$

Equivalent slenderness ratio (Formula [15], above):

$$\frac{KL}{r} = 0.29\frac{h}{t} = 0.29 \times \frac{60.5}{0.375} = 46.8$$

From Table 4a, page 48, C=68. Since $\frac{KL}{r} < 68$, formula (2), page 112, applies; buckling stress is

$$f_B = B - D\left(\frac{KL}{r}\right) = 39.9 - 0.263 \times 46.8 = 27.6 \text{ kips per sq in.}$$

Bending moment to cause web buckling is

$$\frac{f_B I}{c} = \frac{27.6 \times 57{,}860}{30.25} = 52{,}800 \text{ in.-kips}$$

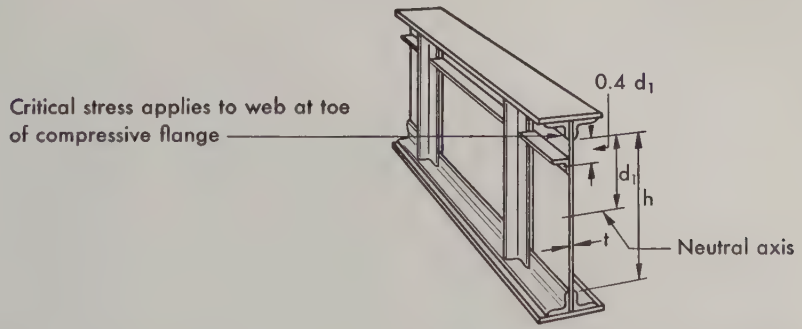
By comparison with Example 15, page 142, it is noted that the addition of a horizontal stiffener has increased the buckling resistance of the web more than 150 per cent.

Flat Plates under Combined Stresses

Flat plate panels are often subjected to combined stresses in the plane of the plate. For example, the web of a beam or girder must usually resist both shear and bending in the plane of the web. If the member must also carry axial forces, then a uniform edge compressive stress is superimposed on the shear and bending stresses.

TABLE 21

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Flat Plates in Bending in the Plane of the Plate



$\frac{h}{t}$	$\frac{KL}{r}$			$\frac{h}{t}$	$\frac{KL}{r}$		
	Without Horizontal Stiffener		With Horizontal Stiffener		Without Horizontal Stiffener		With Horizontal Stiffener
	Unloaded Edges Fixed	Unloaded Edges Simply Supported	Unloaded Edges Simply Supported		Unloaded Edges Fixed	Unloaded Edges Simply Supported	Unloaded Edges Simply Supported
10	5.2	6.7	2.9	120	62.4	80.4	34.8
20	10.4	13.4	5.8	140	72.8	93.8	40.6
30	15.6	20.1	8.7	160	83.2	107.2	46.4
40	20.8	26.8	11.6	180	93.6	120.0	52.2
50	26.0	33.5	14.5	200	104.0	134.0	58.0
60	31.2	40.2	17.4	220	114.4	147.4	63.8
70	36.4	46.9	20.3	240	124.8	160.8	69.6
80	41.6	53.6	23.2	260	135.2	174.2	75.4
90	46.8	60.3	26.1	280	145.6	187.6	81.2
100	52.0	67.0	29.0	300	156.0	201.0	87.0

Combinations of stress that will cause buckling of flat plate panels may be found from the following formula:

$$\frac{f_c}{f_C}+\left(\frac{f_b}{f_B}\right)^2+\left(\frac{f_s}{f_S}\right)^2=1 \qquad (16)$$

where f_c = uniform edge compressive stress in plate, kips per sq in.

f_C = critical stress for plate under edge compression alone, kips per sq in. (see formulas [7a] and [7b], page 131)

f_b = maximum compressive stress in clear height caused by bending in plane of plate, kips per sq in.

f_B = critical stress for plate under bending alone, kips per sq in. (see formulas [13] and [14], page 142)

f_s = average shear stress in plate, kips per sq in.

f_S = critical stress for plate under uniform shear alone, kips per sq in. (see formulas [11] and [12], page 140).

In the above formula, the stresses are assumed to be combined in the same way that they would be combined in the web of a beam-column under axial load and bending. That is, the direct stress at one edge of the panel, parallel to the edge, is (f_c+f_b) and at the opposite edge the direct stress is (f_c-f_b). The shear stress f_s occurs on planes parallel and perpendicular to the direction of f_c and f_b.

If, for any combination of stresses f_c, f_b and f_s, the terms on the left side of formula (16) total less than unity, the plate will not buckle under the given system of stresses. If the formula is used to check whether a plate panel will carry the working stresses with a certain safety factor against buckling, the values of f_c, f_b and f_s to be used in the formula should be equal to the factor of safety times the working stresses. Then if the sum on the left side of formula (16) is equal to, or less than, unity, the factor of safety is equal to or greater than the prescribed value.

Example 17. Check the web of the girder used in Example 14, page 140, to determine whether the girder can carry a combined shear of 60 kips and a bending moment of 10,000 in.-kips with a factor of safety of 1.5 against buckling of the web under combined stresses. Assume that no horizontal stiffener is used.

Average shear stress on web $=\frac{60}{72\times 0.375}=2.22$ kips per sq in.

Bending stress at toe of compression flange $=\frac{Mc}{I}=\frac{10{,}000\times 30.25}{57{,}860}=5.23$ kips per sq in.

Critical shear stress, f_S, (from Example 14, page 140) $=5.68$ kips per sq in.

Critical bending stress, f_B, (from Example 15, page 142) $=10.9$ kips per sq in.

Edge compression, f_c, is zero.

Multiply the actual stresses by the required factor of safety to determine f_s and f_b.

$$f_s = 2.22 \times 1.5 = 3.33 \text{ kips per sq in.}$$

$$f_b = 5.23 \times 1.5 = 7.84 \text{ kips per sq in.}$$

Using the combined stress formula (16), page 145,

$$\frac{f_c}{f_C} + \left(\frac{f_b}{f_B}\right)^2 + \left(\frac{f_s}{f_S}\right)^2 = 1$$

$$0 + \left(\frac{7.84}{10.9}\right)^2 + \left(\frac{3.33}{5.68}\right)^2 = 0.517 + 0.344 = 0.861$$

Since the above sum is less than unity, the combination of the stresses is not critical and the factor of safety is greater than 1.5.

Alclad Plates

Frequently the cladding material used on alclad sheet and plate is not as strong as the core material. The effect of this factor on buckling strength depends upon the type of buckling involved. In the case of over-all buckling of a beam or column fabricated from alclad plate (as opposed to local buckling of the plate), an approximate correction to take account of this reduction in strength may be made by decreasing the radius of gyration, or the equivalent radius of gyration for a beam (formulas [4a] to [5b], pages 118 and 119), according to the following formula:

$$r_{alclad} = H(r_{nonclad}) \qquad (17)$$

where r_{alclad} = radius of gyration or equivalent radius of gyration for a column or beam fabricated from alclad plate, in.

$r_{nonclad}$ = radius of gyration or equivalent radius of gyration for the same column or beam made of nonclad plate, in.

H = factor depending upon the alloy and thickness of the plate.

Values of the factor H for various alclad plate alloys are listed in the last column of Table 13, page 90. The modified radius of gyration from formula (17) is used with the effective length, KL, to determine an effective slenderness ratio which is substituted into the column formula for the material in question (formula [1] or [2], pages 111 and 112) to determine buckling strength.

The above correction should be made only if most of the member's resistance to buckling is furnished by the alclad plate. Where an appreciable part of the stiffness is provided by nonclad parts, the effect of the cladding is negligible and no correction need be made.

The relative weakness of the cladding material has a greater effect on local buckling of plates than on over-all buckling of beams and columns because of the location of the cladding at the outer fiber of

the plate. To take approximate account of this effect, the equivalent slenderness ratio for local buckling should be modified as indicated in the following formula

$$\left(\frac{KL}{r}\right)_{alclad} = \frac{1}{H^2}\left(\frac{KL}{r}\right)_{nonclad} \qquad (18)$$

where $\left(\frac{KL}{r}\right)_{alclad}$ = equivalent slenderness ratio for local buckling of alclad plate, in.

$\left(\frac{KL}{r}\right)_{nonclad}$ = equivalent slenderness ratio for local buckling of nonclad plate of same dimensions, in.

H = factor depending upon the alloy of the plate, same as in formula (17) (see Table 13, page 90).

The modified equivalent slenderness ratio from formula (18) is used with the buckling formulas for the alloys in question (formulas [1] and [2] for compressive buckling and formulas [9] and [10] for shear buckling) to determine the local buckling stress for the alclad plate.

Example 18. Calculate the local buckling stress for the $\frac{9}{16}$-in. plate in Example 12, page 134, if the plate is Alclad 2014-T6 alloy.

From Example 12, $\left(\frac{KL}{r}\right)_{nonclad} = 69.3$

From Table 13, page 90, H = 0.99

From formula (18) above,

$$\left(\frac{KL}{r}\right)_{alclad} = \frac{1}{(0.99)^2} \times 69.3 = 70.7$$

Local buckling stress is (formula [1], page 111):

$$f_C = \frac{102{,}000}{(70.7)^2} = 20.4 \text{ kips per sq in.}$$

Stiffeners for Flat Plates

When aluminum alloy flat plates or sheets are used in construction, it is frequently advantageous to increase the buckling strength of the plate by means of stiffeners that divide the plate into smaller panels, rather than to make the plate thick enough to carry the load without the aid of stiffeners. In the following paragraphs some rules are given for determining the size of stiffeners to use with plates under various conditions of loading.

In each case the size of stiffener required is expressed in terms of the desired critical stress or critical load for the plate-stiffener combination. If the designer wishes to make the stiffeners just large enough so that the stress that will cause them to buckle is the same as the stress that will cause the plate panels between stiffeners to buckle, then the critical stress or load to use in designing the stiffeners is the critical stress or load for the plate panels.

It sometimes happens that for practical reasons the plate is "overdesigned"; that is, the plate is thicker than would be necessary, or the stiffeners are closer together than would be necessary, to achieve the required factor of safety against plate buckling. In these cases the critical stress or load that the stiffeners are designed to develop need not be as great as the critical value for the individual plate panels.

In other cases, where a relatively small factor of safety against plate buckling is used, it may be desirable to give the stiffeners an extra margin of strength to prevent their collapsing as soon as the plate between stiffeners begins to buckle. In these cases the "desired critical stress" or "desired critical load" used in proportioning the stiffeners will be greater than the buckling stress or load for the plate between stiffeners.

Sometimes stiffeners are composed of a pair of members of equal size on both sides of the plate, whereas in other designs a stiffener is a single member on one side of the plate. For a stiffener composed of a member on one side only, the moment of inertia is taken about the face of the plate in contact with the stiffener, and the distance between stiffeners is taken as the distance between rivet lines. For stiffeners composed of members on both sides of the plate, the moment of inertia is taken about the center line of the plate and the distance between stiffeners is taken as the clear distance.

Stiffeners for Flat Plate Shear Panels

The first case considered under the design of stiffeners for flat plate panels is the use of stiffeners to increase the resistance to buckling of flat shear panels. Since this problem arises most frequently in connection with transverse stiffeners on plate-girder webs, the formulas are presented in a form best adapted to this problem. The panel dimensions are given as "h," the clear height, and "s," the stiffener spacing, rather than in terms of the "a" and "b" dimensions used in formulas (11) and (12), page 140, for shear buckling stress of flat panels.

The moment of inertia, I_S, required for transverse stiffeners of beam and girder webs to resist shear buckling of the web is given by the formula

$$I_S = 55 \times 10^{-6} \frac{f_S h^3 t \left(\frac{s}{h}\right)}{1 + 5\left(\frac{s}{h}\right)^3} \qquad (19)$$

where I_S = required moment of inertia of transverse stiffener, in.^{4},

f_S = desired critical shear stress for web, kips per sq in.

h = clear height of web, in.

t = thickness of web, in.

s = distance between stiffeners, in.

Table 22, page 150, will be found helpful in arriving at the proper moments of inertia of stiffeners used to prevent buckling in shear panels.

Example 19. Design transverse stiffeners to develop the full shear buckling strength in the web of the girder shown in Example 14, page 140.

The required moment of inertia for each vertical stiffener is (formula [19] page 148)

$$I_S = \frac{55 \times 10^{-6} f_S h^3 t (s/h)}{1 + 5 (s/h)^3}$$

From Example 14, $f_S = 5.68$ kips per sq in.

$$I_S = \frac{55 \times 10^{-6} \times 5.68 \times (60.5)^3 \times 0.375 \left(\frac{48}{60.5}\right)}{1 + 5 \left(\frac{48}{60.5}\right)^3} = 5.89 \text{ in.}^4$$

Try a $3\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ angle with the $3\frac{1}{2}''$ leg outstanding.

Moment of inertia about face of web (allowing for a $\frac{1}{2}''$ filler plate between stiffener angle and web) is

$$I = 2.12 + 1.77 \ (1.62)^2 = 6.77 \text{ in.}^4$$

This stiffener is satisfactory.

When a transverse stiffener is at a point of bearing in a shear panel such as a girder web, the bearing load that the stiffener will withstand may be calculated from the formula

$$P = 180{,}000 \frac{(I - I_S)}{h^2} \qquad (20)$$

where P = bearing load the stiffener will withstand, kips

I = moment of inertia of stiffener, in.^{4}

I_S = moment of inertia required to resist shear buckling (formula [19]), in.^{4}

h = clear height of web, in.

To determine an allowable bearing load for a stiffener, an appropriate factor of safety should be applied to the load given by formula (20).

Beams and girders with flat shear panels have a considerable reserve of resistance against collapse, even after the panels have buckled, because of tension-field action. Advantage is often taken of this fact by reducing the factor of safety against plate buckling. Where this is done the value of f_S used in formula (19), page 148,

TABLE

22 Moment of Inertia of Stiffeners for Beam and Girder Webs

t = thickness of web, in.
h = height of web, in.
s = spacing of transverse stiffeners, in.
C_1 and C_2 are coefficients

Transverse Stiffeners

$I_S = 10^{-6} C_1 f_S t h^3$

I_S = required moment of inertia of stiffener, in.^{4}

f_S = desired shear buckling strength for web, kips per sq in.

Longitudinal Stiffeners

$I_L = 10^{-6} C_2 f_B t h^3$

I_L = required moment of inertia, in.^{4}

f_B = desired critical bending strength for web, kips per sq in.

A = gross area of stiffener, in.^{2}

$\frac{s}{h}$	Values of Coefficient C_1	Values of Coefficient C_2				
		$\frac{A}{ht} = 0$	$\frac{A}{ht} = 0.05$	$\frac{A}{ht} = 0.10$	$\frac{A}{ht} = 0.15$	$\frac{A}{ht} = 0.20$
0.1	5.5	0.41	0.41	0.42	0.42	0.42
0.2	10.6	0.44	0.45	0.46	0.48	0.49
0.3	14.5	0.49	0.52	0.54	0.57	0.60
0.4	16.7	0.56	0.61	0.66	0.70	0.75
0.5	16.9	0.65	0.72	0.80	0.88	0.95
0.6	15.9	0.76	0.87	0.98	1.08	1.19
0.7	14.2	0.89	1.04	1.18	1.33	1.48
0.8	12.4	1.04	1.23	1.42	1.62	1.81
0.9	10.7	1.21	1.45	1.70	1.94	2.18
1.0	9.2	1.40	1.70	2.00	2.30	2.60
1.2	6.8	1.84	2.27	2.70	3.14	3.57
1.4	5.2	2.36	2.95	3.54	4.12	4.71
1.6	4.1	2.96	3.73	4.50	5.26	6.03
1.8	3.3	3.64	4.61	5.58	6.56	7.53
2.0	2.7	4.40	5.60	6.80	8.00	9.20

should be the required ultimate shear strength of the web rather than the buckling stress for the web panels. Also the stiffener must be connected to the flanges of the beam or girder so that load can be transmitted from the flange to the stiffener. Transverse stiffeners, designed as indicated in Table 22, above, can be counted on to resist a moderate amount of tension-field action in the web. Where the full diagonal-tension strength of the web is needed, however, the transverse stiffeners should be specially designed in accordance with aircraft structural practice.[1]

[1] See, for example, P. Kuhn, J. P. Peterson and L. R. Levin, "A Summary of Diagonal Tension—Part I, Methods of Analysis," *Technical Note* 2661, National Advisory Committee for Aeronautics, 1952.

Stiffeners for Flat Plates in Bending in the Plane of the Plate

The moment of inertia required for a longitudinal stiffener, such as that shown in the sketch in Table 21, page 144, to resist buckling of a beam or girder web under the influence of bending stresses in the plane of the web, is

$$I_L = 10^{-6} f_B t h^3 \left[\left(1 + 6 \frac{A}{ht} \right) \left(\frac{s}{h} \right)^2 + 0.4 \right] \qquad (21)$$

where I_L = required moment of inertia of longitudinal stiffener, in.^{4}

f_B = desired critical bending stress for web, kips per sq in.

A = gross area of cross section of the stiffener (area of the stiffener alone, not including any of the attached plate), sq in.

h, t and s are as previously defined, for formula (19), page 148.

The above equation requires a trial and error solution since both the moment of inertia I_L and the area A of the stiffener are unknown. It is generally convenient to assume, as a first approximation, that the ratio A/ht has the value 0.1. Table 22, page 150, will be found helpful in connection with the use of formula (21) above.

Example 20. Design a horizontal stiffener for the girder in Examples 14 and 15, pages 140 and 142, to insure that buckling of the web because of bending stresses in the plane of the web does not occur at a maximum bending moment of 22,000 in.-kips.

From Example 15, the moment of inertia of the girder is 57,860 in.^{4}

The maximum bending stress at the toe of the compression flange is

$$f_B = \frac{Mc}{I} = \frac{22{,}000 \times 30.25}{57{,}860} = 11.5 \text{ kips per sq in.}$$

Try a $2\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{4}''$ angle with the $2\frac{1}{2}''$ leg outstanding.

Check this stiffener by means of formula (21) above, and Table 22, page 150.

$$\frac{s}{h} = \frac{48}{60.5} = 0.79, \quad \frac{A}{ht} = \frac{0.94}{60.5 \times 0.375} = 0.041$$

By interpolation from Table 22, page 150, $C_2 = 1.18$

The required moment of inertia is

$$I_L = 10^{-6} \times 1.18 \times 11.5 \times 0.375 \, (60.5)^3 = 1.12 \text{ in.}^4$$

The moment of inertia of the selected angle is

$$I = 0.59 + 0.94 \, (0.86)^2 = 1.29 \text{ in.}^4$$

Since this moment of inertia exceeds the required value, the stiffener is satisfactory.

Stiffeners for Flat Plates in Edge Compression

Stiffeners may often be used effectively on a plate loaded in edge compression, such as the compression flange of a box beam or a plate

element of a column. Longitudinal stiffeners (that is, stiffeners with axes parallel to the direction of the main compressive stress in the plate) can be treated as columns, and the compressive stress that will cause them to buckle can be determined from the column formulas (1) and (2), pages 111 and 112.

In computing the radius of gyration of a longitudinal stiffener for use in the column formulas, the stiffener should be considered to consist of the stiffening member itself plus a width of attached sheet equal to the spacing between stiffeners. The effective length of the stiffener may generally be taken to be KL, where L is the distance between points at which the stiffener is supported against movement in a direction normal to the plane of the plate. The value of K depends upon the conditions of restraint at the points of support (see pages 112 and 114).

In the case of long panels with relatively few stiffeners, the effective length may be less than that described above because of the restraining effect of the plate. The reduced effective length for such stiffeners is given by formula (22) below. This reduced effective length, KL′, should be used whenever its value is less than the actual KL for the stiffener.

$$KL' = sN_P^2\sqrt{1+\frac{A}{st}-\frac{1}{N_P^2}} \qquad (22)$$

where KL′ = reduced effective length of longitudinal stiffener, in.

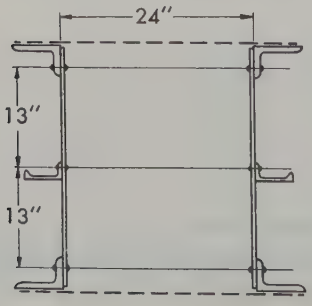
N_P = total number of panels into which the longitudinal stiffeners divide the plate

s = distance between longitudinal stiffeners, in.

A = gross area of cross section of longitudinal stiffener, sq in. (area of stiffener alone, not including any of the attached plate)

t = thickness of plate, in.

Example 21. Redesign the column in Example 13, page 136, using thinner plates with longitudinal stiffeners to reinforce the plates



	Area
4—L 6″ x 4″ x 5/8″	23.40
2— Pl. 30½″ x 7/16″	26.69
2—Bulb L 5″ x 2½″	4.26
	54.35 in.²

against local buckling. Assume material, load requirements and the slenderness ratio for the column as a whole remain unchanged. Try the section shown in the sketch.

Average compressive stress on column at load of 1500 kips:

$$\frac{P}{A}=\frac{1500}{54.35}=27.6 \text{ kips per sq in.}$$

For local buckling of plate, assume

$$\frac{KL}{r}=1.5\frac{b}{t}=1.5\times\frac{13}{7/16}=44.6$$

From formula (2), page 112, and Table 4a, page 48, buckling stress for plate is

$$f_C=B-D\frac{KL}{r}=39.9-0.263\times 44.6=28.2 \text{ kips per sq in.}$$

From Example 13, page 136, the buckling stress for the column as a whole is 29.4 kips per sq in. Since the average stress at a load of 1500 kips is less than this value and also less than the buckling stress for the plate, the column is satisfactory, provided that the stiffeners are adequate.

Radius of gyration of stiffener about axis through centroid, r_x (assume 13-in. width of plate acts with stiffener, see page 152):

Section	Area, Sq In.	For Axis at Outside Face of Plate			I_o In.^{4}
		y In.	Ay In.^{3}	Ay^2 In.^{4}	
Bulb angle 5″ × 2½″	2.13	2.15	4.58	9.85	7.10
Plate 7/16″ × 13″	5.69	−0.219	−1.25	0.27	0.09
	7.82		3.33	10.12	7.19

$$\bar{y}=\frac{3.33}{7.82}=0.43 \text{ in.}$$

$$I_x=10.12+7.19-0.43\times 3.33=15.88 \text{ in.}^4$$

$$r_x=\sqrt{\frac{15.88}{7.82}}=1.42 \text{ in.}$$

Effective length of stiffener (formula [22], page 152):

$$KL'=sN_P^2\sqrt{1+\frac{A}{st}-\frac{1}{N_P^2}}$$

$$=13(2)^2\sqrt{1+\frac{2.13}{13\times 7/16}-\frac{1}{(2)^2}}=55.1 \text{ in.}$$

Effective slenderness ratio for stiffener:

$$\frac{KL'}{r}=\frac{55.1}{1.42}=38.8$$

From formula (2), page 112, and Table 4b, page 51, (extruded shapes), the buckling strength of the stiffener is

$$f_C=B-D\frac{KL}{r}=38.3-0.202\times 38.8=30.5 \text{ kips per sq in.}$$

This stress is greater than the stress required (27.6 kips per sq in.), so the stiffeners are satisfactory.

If a plate in edge compression is reinforced by transverse stiffeners

rather than longitudinal stiffeners, the moment of inertia required for the transverse stiffeners is

$$I_T = 2\times10^{-6}\frac{P_{cr}b^3}{L}\left(2-\frac{1}{N_T}\right) \qquad (23)$$

where I_T = moment of inertia of transverse stiffener, in.^{4}

P_{cr} = desired critical load for panel between stiffeners, kips

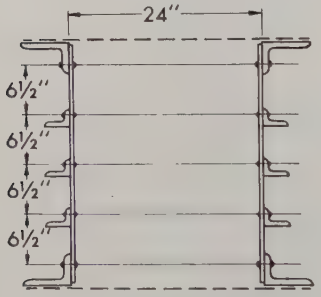
b = width of panel (length of transverse stiffeners), in.

L = length of panel (spacing of transverse stiffeners), in.

N_T = number of transverse stiffeners.

When plates are reinforced with a combination of longitudinal and transverse stiffeners, the moment of inertia determined from formula (23) should be multiplied by $\left(1+\frac{1}{N_L}\right)$, where N_L is the number of longitudinal stiffeners in a panel.

Example 22. Design a 6061-T6 column having the same outside dimensions and same slenderness ratio as the columns in Examples 13, page 136, and 21, page 152, to carry a load of 500 rather than 600 kips with a safety factor of 2.5. Try the section shown in the sketch.



	Area
4—Ls 6" x 4" x 9/16"	21.20
2—Pl. 30½" x ¼"	15.25
6—Ls 3" x 2" x ¼"	7.14
	43.59 in.^{2}

To carry 500 kips with a safety factor of 2.5, the column must have an ultimate strength of at least $500\times2.5=1250$ kips. The average compressive stress at this load is

$$\frac{P}{A}=\frac{1250}{43.59}=28.7 \text{ kips per sq in.}$$

For local buckling of plate, assume

$$\frac{KL}{r}=1.5\frac{b}{t}=1.5\times\frac{6.5}{\frac{1}{4}}=39.0$$

From formula (2), page 112, and Table 4a, page 48, buckling stress for plate is

$$f_C=39.9-0.263\times39.0=29.6 \text{ kips per sq in.}$$

For local buckling of outstanding legs of angles, assume

$$\frac{KL}{r}=4\frac{b}{t}.$$

For 6" × 4" × 9/16" angles, $\frac{KL}{r}=4\frac{(6-\frac{9}{16})}{\frac{9}{16}}=38.7$

For 3" × 2" × ¼" angles, $\frac{KL}{r}=4\frac{(3-\frac{1}{4})}{\frac{1}{4}}=44.0$

From formula (2), page 112, and Table 4c, page 52, controlling buckling stress for outstanding legs of angles is

$f_C = 38.3 - 0.202 \times 44.0 = 29.4$ kips per sq in. for $3'' \times 2'' \times \frac{1}{4}''$ angles.

From Example 13, page 136, the buckling strength of the column as a whole is 29.4 kips per sq in. Since the buckling stress for the column as a whole and the local buckling stresses for the plates and angles are all greater than 28.7 kips per sq in., the section chosen is adequate, provided that the stiffeners are capable of carrying the 28.7 kips per sq in. average stress on the column.

Radius of gyration of longitudinal stiffeners about axis through centroid, r_x (assume 6.5 in. width of plate acts with each stiffener, see page 152).

Section	Area, Sq In.	For Axis at Outside Face of Plate			I_o In.^{4}
		y In.	Ay In.^{3}	Ay^2 In.^{4}	
Angle $3'' \times 2'' \times \frac{1}{4}''$	1.19	0.97	1.15	1.12	1.06
Plate $\frac{1}{4}'' \times 6\frac{1}{2}''$	1.62	−0.125	−0.20	0.03	0.01
	2.81		0.95	1.15	1.07

$$\bar{y} = \frac{0.95}{2.81} = 0.34 \text{ in.}$$

$$I_x = 1.15 + 1.07 - 0.95 \times 0.34 = 1.90 \text{ in.}^4$$

$$r_x = \sqrt{\frac{1.90}{2.81}} = 0.82 \text{ in.}$$

Effective length of longitudinal stiffeners (formula [22], page 152):

$$KL' = 6.5\ (4)^2 \sqrt{1 + \frac{1.19}{6.5 \times 0.25} - \frac{1}{(4)^2}} = 134 \text{ in.}$$

Effective slenderness ratio of longitudinal stiffeners (without transverse stiffeners)

$$\frac{KL'}{r} = \frac{134}{0.82} = 163.$$

The effective slenderness ratio of the longitudinal stiffeners is too large to enable them to carry a compressive stress of 28.7 kips per sq in., so it is necessary to reduce their effective length by adding transverse stiffeners. The spacing required may be determined by substituting the desired critical stress for the longitudinal stiffeners in the column formula (see formula [2], page 112, and Table 4c, page 52). Assume K=0.9.

$$f_C = 38.3 - 0.202 \frac{KL}{r}$$

$$L = (38.3 - f_C) \frac{r}{0.202K}$$

$$= (38.3 - 28.7) \frac{0.82}{0.202 \times 0.9} = 43.3 \text{ in.}$$

Assume that the length of the column between end gusset plates is 40 feet. Divide this length into 12 panels by inserting 11 transverse stiffeners 40 in. apart. The required moment of inertia of the transverse stiffeners is calculated from formula (23), page 154. The value of P_{cr} to be used in the formula is equal to the desired buckling

stress times the sum of the area of the stiffeners and the area of plate in the panels.

$$P_{cr}=28.7\ (26\times\tfrac{1}{4}+3\times 1.19)=289\text{ kips}$$

$$I_T=2\times 10^{-6}\frac{P_{cr}b^3}{L}\left(2-\frac{1}{N_T}\right)\left(1+\frac{1}{N_L}\right)$$

$$=2\times 10^{-6}\frac{289(26)^3}{40}\left(2-\frac{1}{11}\right)\left(1+\frac{1}{3}\right)=0.65\text{ in.}^4$$

Try a $2\tfrac{1}{2}''\times 1\tfrac{1}{2}''\times\tfrac{3}{16}''$ angle with the $2\tfrac{1}{2}''$ leg outstanding. The moment of inertia about the face of the sheet is

$$I=0.46+0.72\ (0.84)^2=0.97\text{ in.}^4$$

This transverse stiffener will be satisfactory.

Stiffeners loaded in compression, such as those designed by formulas (21) and (22), pages 151 and 152, must not only have a sufficiently large moment of inertia to prevent column bending failure but must also resist local buckling. Local buckling of stiffeners in compression should be checked by the methods outlined on pages 130 to 137. The strength of relatively thin Z, T or bulb-angle stiffeners may in some cases be governed by torsion failure. Methods for calculating the critical loads for stiffeners that fail by twisting may be found in technical literature.①

Curved Plates and Tubes in Edge Compression

Curved plates and tubes are better suited for resisting local buckling failure than are flat plates, and consequently the critical stresses are higher for a given thickness and width. Critical stresses for curved plates in edge compression are considerably affected by variations in curvature and straightness. The following formula gives equivalent slenderness ratios, KL/r, which, when used with the column formulas (1) and (2), pages 111 and 112, result in critical stresses that are conservative in comparison with the results of most tests on curved plates and cylinders in edge compression:

$$\frac{KL}{r}=4\sqrt{\frac{R}{t}}\left(1+\frac{\sqrt{R/t}}{35}\right) \qquad (24)$$

where $\frac{KL}{r}$ = equivalent slenderness ratio for curved plate, tube or cylinder,

R = mean radius of curvature, in.

t = thickness of plate, tube or cylinder wall, in.

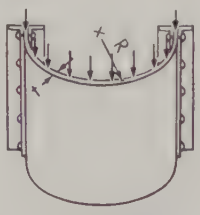
Sometimes stiffeners are added to curved plates to divide the surface into panels. In the case of such curved plate panels loaded in edge compression, the equivalent slenderness ratio should be

① See, for example, E. E. Lundquist and C. M. Fligg, "A Theory for Primary Failure of Straight Centrally Loaded Columns," *Technical Report* 582, National Advisory Committee for Aeronautics, 1937;

Also, Friedrich Bleich, *The Buckling Strength of Metal Structures*, Chapter III, McGraw-Hill Book Co., Inc., New York, 1952.

TABLE 23

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Curved Plates, Cylinders and Tubes in Edge Compression



Curved Plates

Seamless Tubes

$$\frac{KL}{r} = 4\sqrt{\frac{R}{t}}\left(1+\frac{\sqrt{R/t}}{35}\right)$$

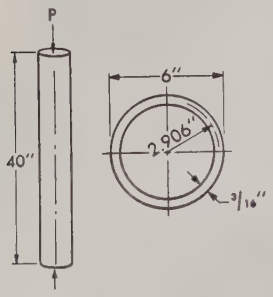
$$\frac{R}{t} = \frac{\text{radius of curvature}}{\text{thickness of shell}}$$

$\frac{R}{t}$	$\frac{KL}{r}$	$\frac{R}{t}$	$\frac{KL}{r}$	$\frac{R}{t}$	$\frac{KL}{r}$
5	9.5	110	54.5	450	136.3
10	13.8	120	57.5	500	146.6
15	17.2	130	60.5	550	156.7
20	20.2	140	63.3	600	166.6
25	22.9	150	66.1	650	176.3
30	25.3	160	68.9	700	185.8
35	27.7	170	71.6	750	195.3
40	29.9	180	74.2	800	204.6
45	32.0	190	76.8	850	213.8
50	34.0	200	79.4	900	222.9
55	35.9	220	84.5	1000	240.8
60	37.8	240	89.4	1100	258.4
65	39.7	260	94.2	1200	275.7
70	41.5	280	98.9	1300	292.8
75	43.2	300	103.6	1400	309.7
80	44.9	320	108.1	1500	326.4
85	46.6	340	112.6	1600	342.9
90	48.2	360	117.0	1700	359.2
95	49.8	380	121.4	1800	375.4
100	51.4	400	125.7	1900	391.5

determined by formula (24), page 156, but need not be taken greater than the equivalent slenderness ratio for a flat plate panel of the same dimensions (see pages 130 to 134).

Table 23, page 157, gives values of equivalent slenderness ratio corresponding to various values of R/t for curved plates, cylinders and tubes in edge compression, calculated from formula (24).

Example 23. Determine the strength of the 6061-T6 seamless tubular compression member shown in the sketch.



Failure as a column (assume K=0.8)

r=2.056 (From Table 57, page 267)

$$\frac{KL}{r}=\frac{0.8\times 40}{2.056}=15.6$$

Failure by local buckling

$$\frac{R}{t}=\frac{2.906}{0.1875}=15.5$$

$\frac{KL}{r}=17.5$ (by interpolation from Table 23, page 157).

The compression strength is controlled by local buckling. From Table 4g, page 59, C=63. Since KL/r < 63, use formula (2), page 112 (constants B and D from Table 4g, page 59).

$$f_C=B-D\frac{KL}{r}=38.3-0.202\times 17.5=34.8 \text{ kips per sq in.}$$

The load P which will cause failure by local buckling is 34.8 × Area = 34.8 × 3.424 = 119 kips.

Curved Plates and Tubes in Bending

The critical stress on the compression side of thin-walled tubes or cylinders in bending can be computed by the method described in the preceding section, using formula (24), page 156, and formulas (1) and (2), pages 111 and 112. When the tube or cylinder has a small R/t ratio so that the critical bending stress is well into the plastic stress range, the above procedure gives critical stresses that are very conservative. The critical bending stress for such tubes and cylinders fabricated of aluminum alloys 2024-T3 and 6061-T6 should be computed from the following empirical formulas:

Alloy	Formula	Upper Limiting Value of R/t to which Formula Applies	Formula Number
2024-T3	$f_B=74-0.51\frac{R}{t}$	85	(25a)
6061-T6	$f_B=55-0.42\frac{R}{t}$	58	(25b)

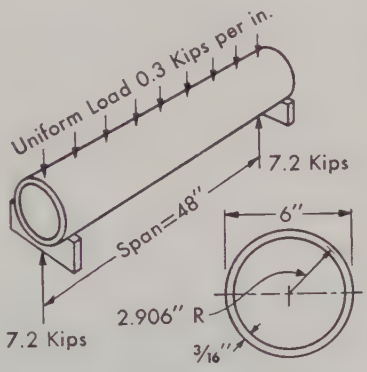
where f_B = nominal critical compressive stress for a tube or cylinder in bending (Mc/I), kips per sq in.

R and t are as defined for formula (24), page 156.

Formulas 25a and 25b, page 158, do not apply for solid round sections, $R/t = \frac{1}{2}$. The bending strength of such sections may be calculated by using the formula given in Table 14, page 100.

When the ratio R/t exceeds the upper limiting value given with formulas (25a) and (25b), page 158, formula (24), page 156, should be used in conjunction with the formulas for column strength to calculate the critical bending stress.

Example 24. Check the 6061-T6 seamless tubular beam shown in the sketch to determine the factor of safety against buckling.



Maximum moment $= \frac{0.3 \times (48)^2}{8} = 86.4$ in.-kips.

Calculated compressive stress (section modulus S from Table 57, page 267):

$$f = \frac{M}{S} = \frac{86.4}{4.825} = 17.9 \text{ kips per sq in.}$$

$$\frac{R}{t} = \frac{2.906}{0.1875} = 15.5$$

Since R/t is less than 58, formula (25b), page 158, may be used to calculate the critical bending stress.

$$f_B = 55 - 0.42 \times \frac{R}{t}$$

$$f_B = 55 - 0.42 \times 15.5 = 48.5 \text{ kips per sq in.}$$

Factor of safety against buckling $= \frac{48.5}{17.9} = 2.71$.

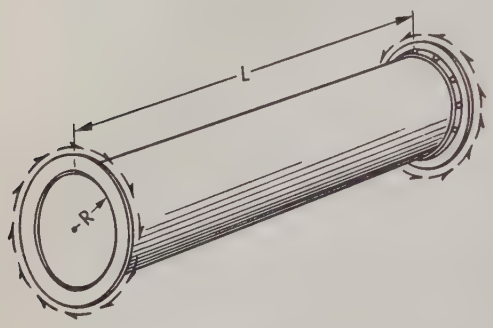
The buckling of unstiffened tubes and cylinders in edge compression or bending will precipitate complete collapse. For this reason, an adequate factor of safety should always be used in problems involving such members. Curved plates and cylinders with longitudinal stiffeners may or may not collapse on first buckling, depending upon how much reserve strength is built into the stiffeners. This problem is similar to that of the collapse of flat-plate panels and may be handled by the effective-width method discussed on pages 135 and 136.

Curved Plates and Tubes in Shear

Cylinders, tubes and curved plates loaded in transverse bending or torsion may buckle in shear. Shear buckling stresses can be found from formulas (9) and (10), page 137, if the proper value of equivalent slenderness ratio is used. Values of equivalent slenderness ratio

TABLE 24

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Tubes and Cylinders in Shear



R = mean radius of cylinder, in.
t = thickness of shell, in.
L = clear length between circumferential stiffeners, in.

$\frac{L}{R}$	$\frac{R}{t}$=5	$\frac{R}{t}$=10	$\frac{R}{t}$=15	$\frac{R}{t}$=20	$\frac{R}{t}$=25	$\frac{R}{t}$=30	$\frac{R}{t}$=35	$\frac{R}{t}$=40	$\frac{R}{t}$=45	$\frac{R}{t}$=50
0.2	1.4	2.8	4.2	5.6	7.0	8.4	9.7	11.1	12.5	13.8
0.4	2.8	5.6	8.2	10.8	13.3	15.8	18.1	20.3	22.7	24.8
0.6	4.2	8.1	11.7	15.1	18.3	21.3	24.2	27.0	29.6	32.0
0.8	5.4	10.2	14.5	18.4	21.9	25.2	28.2	31.2	34.0	36.5
1.2	7.6	13.5	18.3	22.7	26.4	30.2	33.4	36.7	39.7	42.5
1.6	9.2	15.6	20.8	25.3	29.4	33.3	36.7	40.2	43.5	46.2
2.0	10.4	17.0	22.5	27.4	31.6	35.5	39.3	42.8	46.3	50.1
2.4	11.3	18.3	24.0	29.0	33.5	37.7	41.9	45.6	49.1	52.4
3.0	12.4	19.6	25.7	30.9	35.9	40.3	44.3	48.2	51.9	55.4
4.0	13.7	21.4	28.1	33.6	38.6	43.3	47.6	51.8	55.7	59.6
5.0	14.6	23.0	29.7	35.5	40.8	45.7	50.4	54.8	59.0	63.0
6.0	15.4	24.1	31.0	37.2	42.7	47.9	52.7	57.3	61.7	65.9
8.0	16.8	25.9	33.4	39.9	45.9	51.5	56.7	61.6	66.3	70.8
12.0	18.6	28.7	36.9	44.2	50.8	56.9	62.7	68.2	73.4	78.4
16.0	20.0	30.8	39.7	47.5	54.6	61.2	67.4	73.2	78.8	84.2
20.0	21.1	32.6	42.0	50.2	57.7	64.7	71.2	77.4	83.4	89.0
30.0	21.2	35.6	46.4	55.6	63.9	71.6	78.8	85.7	92.3	98.5
40.0	21.2	35.6	48.2	59.7	68.7	76.9	84.7	92.1	99.1	105.9
50.0	21.2	35.6	48.2	59.8	70.7	81.1	89.6	97.4	104.8	112.0
60.0	21.2	35.6	48.2	59.8	70.7	81.1	91.1	100.6	109.7	117.2

(Concluded on page 161)

for shear buckling of curved cylinders and tubes of various proportions are listed in Table 24 above. For equivalent slenderness ratio values greater than $\sqrt{50\ R/t}$, the values listed in Table 24 can be

TABLE 24

Values of Equivalent Slenderness Ratio, $\frac{KL}{r}$, for Tubes and Cylinders in Shear—*Concluded*

$\frac{L}{R}$	$\frac{R}{t}=60$	$\frac{R}{t}=70$	$\frac{R}{t}=80$	$\frac{R}{t}=90$	$\frac{R}{t}=100$	$\frac{R}{t}=125$	$\frac{R}{t}=150$	$\frac{R}{t}=175$	$\frac{R}{t}=200$	$\frac{R}{t}=225$
0.2	16.5	19.1	21.7	24.2	26.7	32.7	38.6	44.2	49.7	54.8
0.4	29.0	33.1	36.7	40.5	43.9	52.0	59.6	66.6	73.1	79.3
0.6	36.7	41.2	45.3	49.2	52.9	61.8	70.0	77.7	85.1	91.8
0.8	41.6	46.2	50.7	55.0	58.8	68.4	76.8	85.0	92.5	100.5
1.2	48.0	52.9	58.0	62.4	67.0	77.2	87.6	96.4	104.8	112.8
1.6	52.2	57.7	63.5	68.4	73.0	84.0	94.1	103.6	112.6	121.3
2.0	56.1	61.8	67.2	72.3	77.2	88.8	99.5	109.6	119.1	128.2
2.4	58.7	64.7	70.3	75.7	80.8	92.9	104.1	114.7	124.7	134.2
3.0	62.1	68.4	74.3	80.0	85.5	98.3	110.1	121.3	131.8	141.9
4.0	66.7	73.5	79.9	86.0	91.8	105.6	118.3	130.3	141.6	152.5
5.0	70.6	77.7	84.4	90.9	97.1	111.6	125.1	137.8	149.7	161.2
6.0	73.8	81.3	88.4	95.1	101.6	116.8	130.9	144.2	156.7	168.7
8.0	79.4	87.4	95.0	102.2	109.2	125.6	140.7	154.9	168.4	181.3
12.0	87.8	96.7	105.1	113.2	120.9	138.9	155.7	171.5	186.4	200.6
16.0	94.4	103.9	113.0	121.6	129.9	149.3	167.3	184.2	200.3	215.6
20.0	99.8	109.9	119.4	128.6	137.3	157.9	176.9	194.8	211.8	228.0
30.0	110.4	121.6	132.2	142.3	152.0	174.7	195.8	215.6	234.4	252.3
40.0	118.7	130.7	142.0	152.9	163.3	187.7	210.4	231.7	251.8	271.1
50.0	125.5	138.2	150.2	161.7	172.7	198.5	222.5	245.0	266.3	286.6
60.0	131.3	144.6	157.2	169.2	180.7	207.8	232.8	256.4	278.7	300.0

represented by the formula:

$$\frac{KL}{r}=\sqrt{40\left(\frac{R}{t}\right)^{\frac{3}{2}}U} \qquad (26)$$

where R = mean radius of curvature, in.

t = thickness of shell, in.

U = unity for long, unstiffened cylinders,

$U=\frac{1}{3}\sqrt{\frac{L/R}{\sqrt{R/t}}}$ for cylinders in which the clear length L between circumferential stiffeners is such that the value of U is less than unity.

When a curved plate panel is loaded in shear, as in a cylinder with longitudinal stiffeners under torsion, the equivalent slenderness ratio KL/r to be used in formulas (9) and (10), page 137, for shear buckling is

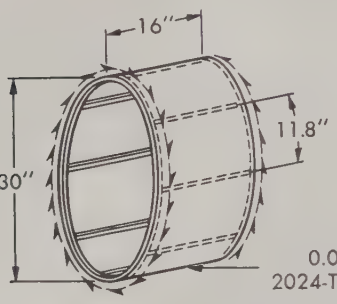
$$\frac{KL}{r}=\frac{Z}{\sqrt{1+\frac{1}{2}\left(\frac{t}{s}\right)^2 Z^2}} \qquad (27)$$

where Z = equivalent slenderness ratio KL/r, for shear buckling of a complete cylinder having the same length, thickness and radius of curvature as the panel (see formula [26], page 161),

t = thickness of plate, in.

s = width of panel between longitudinal stiffeners, in.

Example 25. Check the stiffened cylinder shown in the sketch to determine whether it can carry a torque of 80 in.-kips with a factor of safety of 2.0 against shear buckling of the sheet.



Use formula (26), page 161, to find the equivalent slenderness ratio for shear buckling for the same cylinder without longitudinal stiffeners.

$$U = \tfrac{1}{3}\sqrt{\frac{L/R}{\sqrt{R/t}}} = \tfrac{1}{3}\sqrt{\frac{16/15}{\sqrt{15/0.032}}} = 0.074$$

$$\frac{KL}{r} = \sqrt{40\left(\frac{R}{t}\right)^{\frac{3}{4}}U} = \sqrt{40\left(\frac{15}{0.032}\right)^{\frac{3}{4}}0.074} = 173$$

From formula (27), page 161, find $\frac{KL}{r}$ for one 11.8-in. wide panel.

$$\frac{KL}{r} = \frac{Z}{\sqrt{1+\tfrac{1}{2}\left(\frac{t}{s}\right)^2 Z^2}} = \frac{173}{\sqrt{1+\tfrac{1}{2}\left(\frac{0.032}{11.8}\right)^2 (173)^2}} = 164$$

From Table 4a, page 43, $C_1 = 100$ for 0.032-in. 2024-T4 sheet. Since $\frac{KL}{r} > 100$, formula (9), page 137, applies.

$$f_S = \frac{102{,}000}{\left(\frac{KL}{r}\right)^2} = \frac{102{,}000}{(164)^2} = 3.79 \text{ kips per sq in.}$$

From Table 15a, page 102,

$$f_S = \frac{2R_1T}{\pi(R_1^4 - R_2^4)}$$

For a thin cylinder of mean radius R the above formula is approximately equivalent to

$$f_S = \frac{T}{2\pi R^2 t} = \frac{80}{2\pi(15)^2 0.032} = 1.77 \text{ kips per sq in.}$$

Factor of safety against shear buckling $= \frac{3.79}{1.77} = 2.14$.

The factor of safety is slightly greater than the required value, so the cylinder is satisfactory from the standpoint of shear buckling.

Shear buckling of unstiffened tubes and cylinders precipitates collapse of the member, so an ample factor of safety should be

applied. In a cylinder which is stiffened longitudinally and circumferentially so that the curved sheet is divided into rectangular panels, first buckling of the sheet does not necessarily cause immediate failure, provided the stiffeners are properly designed. This problem is parallel to the problem of tension-field action in flat sheet panels.[1]

CONNECTIONS

Riveted Connections

Foregoing sections of this handbook have dealt with the effect of rivet holes on the strength of aluminum alloy members and with the effect of rivets bearing against aluminum alloy parts (see pages 94 and 99). The discussion of riveted connections which follows, therefore, will be concerned primarily with the shear strength of the rivets themselves. In determining the load required to shear a rivet it is only necessary to multiply the shear strength of the material by the area of the shank of the driven rivet and by the number of shear planes along which the rivet must shear (single shear, double shear, etc.). The most logical value to use for the shank area of the driven rivet is the area of the rivet hole because examinations of many driven rivets by sectioning have shown that the rivets invariably fill the hole if properly driven. Table 25, pages 164 and 165, shows the recommended hole diameters for aluminum alloy rivets and the corresponding shear areas. Bearing areas for various thicknesses of sheet and plate are also given in Table 25.

It is not practicable to list minimum shear strengths for driven rivets. The strength of a driven aluminum alloy rivet is influenced not only by fabrication practices in the plant of the rivet manufacturer but also by the driving technique over which the rivet manufacturer exercises no control. In some aluminum alloy rivets the time interval after driving is also an important variable in establishing the shear strength of the driven rivet. In view of these difficulties, no attempt will be made in this handbook to establish minimum shear strengths for driven rivets; instead a tabulation of average shear strengths, based on tests of laboratory-driven rivets, is given in Table 26, page 166. Experience indicates that these values may be considered representative of properly driven rivets, although occasional individual driven rivets may develop shear strengths on the order of 5 to 10 per cent below the average values listed. For this

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[1] See, for example, P. Kuhn, J. P. Peterson and L. R. Levin, "A Summary of Diagonal Tension—Part I, Methods of Analysis," *Technical Note* 2661, National Advisory Committee for Aeronautics, 1952.

TABLE 25a

Recommended Hole Sizes for Cold-Driven Aluminum Alloy Rivets with Corresponding Shear and Bearing Areas

Nominal Rivet Diameter, In.		1/8	5/32	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
Recommended Hole Diameter, In.		0.1285	0.159	0.191	0.257	0.323	0.386	0.453	0.516	0.578	0.641	0.766	0.891	1.016
Corresponding Drill Size		30	21	11	F	P	W	29/64	33/64	37/64	41/64	49/64	57/64	1 1/64
Corresponding Single Shear Area, Sq In.		0.01296	0.01986	0.02865	0.05187	0.08194	0.1170	0.1612	0.2091	0.2624	0.3227	0.4608	0.6235	0.8107
Sheet and Plate Thicknesses	0.032	0.00411	0.00509	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	0.040	0.00514	0.00636	0.00764	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	0.051	0.00655	0.00811	0.00974	0.01311	.....	.....	.....	.....	.....	.....	.....	.....	.....
	0.064	0.00822	0.01018	0.01222	0.01645	0.0207	.....	.....	.....	.....	.....	.....	.....	.....
	0.081	0.01041	0.01288	0.01547	0.02082	0.0262	0.0313	.....	.....	.....	.....	.....	.....	.....
	0.102	0.01311	0.01622	0.01948	0.02621	0.0329	0.0394	0.0462	.....	.....	.....	.....	.....	.....
	1/8	0.01606	0.01988	0.02388	0.03213	0.0404	0.0483	0.0566	0.0645	0.0723	0.0801	0.0958	0.1114	0.1270
	5/32	.....	0.02480	0.02980	0.04016	0.0505	0.0603	0.0708	0.0806	0.0903	0.1002	0.1197	0.1392	0.1588
	3/16	.....	.....	0.03581	0.04819	0.0606	0.0724	0.0849	0.0968	0.1084	0.1202	0.1436	0.1671	0.1905
	7/32	.....	.....	0.04178	0.05622	0.0707	0.0844	0.0991	0.1129	0.1264	0.1402	0.1676	0.1949	0.2223
	1/4	.....	.....	.....	0.06425	0.0808	0.0965	0.1133	0.1290	0.1445	0.1603	0.1915	0.2228	0.2540
	5/16	.....	.....	.....	.....	0.1009	0.1206	0.1416	0.1613	0.1806	0.2003	0.2394	0.2784	0.3175
	3/8	.....	.....	.....	.....	.....	0.1448	0.1699	0.1935	0.2168	0.2404	0.2873	0.3341	0.3810
	7/16	.....	.....	.....	.....	.....	.....	0.1982	0.2258	0.2529	0.2804	0.3351	0.3898	0.4445
	1/2	.....	.....	.....	.....	.....	.....	.....	0.2580	0.2890	0.3205	0.3830	0.4455	0.5080
	9/16	.....	Bearing Area Sq In.			.....	.....	.....	.....	0.3251	0.3606	0.4309	0.5012	0.5715
	5/8	.....				.....	.....	.....	.....	.....	0.4006	0.4788	0.5569	0.6350
	11/16	.....				.....	.....	.....	.....	.....	0.4407	0.5266	0.6126	0.6985
	3/4	.....				.....	.....	.....	.....	.....	.....	0.5745	0.6683	0.7620
	13/16	.....				.....	.....	.....	.....	.....	.....	.....	0.7239	0.8255
	7/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.7796	0.8890
	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.8910	1.0160

TABLE 25b

Recommended Hole Sizes for Hot-Driven Aluminum Alloy Rivets with Corresponding Shear and Bearing Areas

Nominal Rivet Diameter, In.		3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
Recommended Hole Diameter, In.		0.397	0.469	0.531	0.594	0.656	0.781	0.922	1.063
Corresponding Drill Size		X	15/32	17/32	19/32	21/32	25/32	59/64	1 1/16
Corresponding Single Shear Area, Sq In.		0.1238	0.1728	0.2215	0.2771	0.3380	0.4791	0.6677	0.8875
Sheet and Plate Thicknesses	0.081	0.0322	.....	.....	.....	.....	.....	.....	.....
	0.102	0.0405	0.0478	.....	.....	.....	.....	.....	.....
	1/8	0.0496	0.0586	0.0664	0.0742	0.0820	0.0976	0.1153	0.1329
	5/32	0.0620	0.0733	0.0830	0.0928	0.1025	0.1220	0.1441	0.1661
	3/16	0.0744	0.0879	0.0996	0.1114	0.1230	0.1464	0.1729	0.1993
	7/32	0.0868	0.1026	0.1162	0.1299	0.1435	0.1708	0.2017	0.2325
	1/4	0.0993	0.1173	0.1328	0.1485	0.1640	0.1953	0.2305	0.2658
	5/16	0.1241	0.1466	0.1659	0.1856	0.2050	0.2441	0.2881	0.3322
	3/8	0.1489	0.1759	0.1991	0.2228	0.2460	0.2929	0.3458	0.3986
	7/16	.....	0.2052	0.2323	0.2599	0.2870	0.3417	0.4034	0.4651
	1/2	.....	.....	0.2655	0.2970	0.3280	0.3905	0.4610	0.5315
	9/16	.....	.....	.....	0.3341	0.3690	0.4393	0.5186	0.5979
	5/8	.....	Bearing Area Sq In.		.....	0.4100	0.4881	0.5768	0.6644
	11/16	.....			.....	0.4510	0.5369	0.6339	0.7308
	3/4	.....			.....	.....	0.5858	0.6915	0.7973
	13/16	.....			.....	.....	.....	0.7491	0.8637
	7/8	.....	.....	.....	.....	.....	.....	0.8068	0.9301
	1	.....	.....	.....	.....	.....	.....	.....	1.0630

TABLE 26

Average Ultimate Shear Strengths of Driven Rivets

These values are for rivets driven with cone-point heads. Rivets driven with heads requiring more pressure may be expected to develop slightly higher strengths.

Alloy and Temper① Before Driving	Driving Procedure	Alloy and Temper After Driving	Average Shear Strength, Kips/Sq In.
1100-H14	Cold, as-received	1100-F	11
2017-T4	Cold, as-received	2017-T3	39
2017-T4	Cold, immediately after quenching	2017-T31	34②
2024-T4	Cold, immediately after quenching	2024-T31	42②
2117-T4	Cold, as-received	2117-T3	33
5056-H32	Cold, as-received	5056-H321	30
6053-T61	Cold, as-received	6053-T61	23
6061-T4	Cold, immediately after quenching	6061-T31	24②
6061-T4	Hot, 990° to 1050°F	6061-T43	24②
6061-T6	Cold, as-received	6061-T6	30
7277-T4	Hot, 850° to 975°F	7277-T41	38②

①These designations should be used when ordering rivets.

②Immediately after driving, the shear strengths of these rivets are about 75 per cent of the values shown. On standing at ordinary temperatures, they age harden to develop their full shear strength, this action being completed in about four days for 2017-T31 and 2024-T31 rivets. The values shown for 6061-T31 and 6061-T43 rivets are attained in about two weeks. Values of 26 kips per sq in. are attained by 6061-T31 rivets about four months after driving. The value shown for 7277-T41 rivets is attained in about one week.

reason it is customary to use a slightly larger factor of safety in connection with the shear strength of rivets than is employed for the other parts of an assembly.

Table 27, page 168, gives the load in kips required to produce failure of one rivet in single shear. These values were calculated using the shear strengths from Table 26, above, and the single-shear areas from Table 25, pages 164 and 165.

Tests have shown that if a rivet is used in a relatively thin plate or shape, the high bearing stresses of the plate or shape against the rivet may reduce the effective shear strength of the rivet. Table 28, page 169, shows the reduction in shear strength of aluminum alloy rivets resulting from their use in thin plates and shapes. These reductions should be applied to the shear strengths in Tables 26 and 27 in all cases where the ratio of rivet diameter to plate thickness is in the range indicated.

If a hard rivet is driven in a soft plate, undue distortion of the plate will result. Furthermore, the strength of the rivet is usually wasted because the joint is likely to be governed by the bearing value of the soft plate. Similarly, very soft rivets are not often used in hard plates. It is generally advantageous from a strength standpoint to use a rivet having about the same properties as the material in which it is driven, although from the driving standpoint it is often necessary to have the rivets somewhat softer. The following tabulation gives combinations of alloys and tempers that have been found to work together satisfactorily in many applications.

Structure	Rivets (Driven Tempers)
1100 (any temper), 3003-O, 3004-O, 5052-O	1100-F
3003, 3004 or 5052 (H12 temper or harder)	6053-T61, 6061-T43, 6061-T31
6061-T4, 6061-T6	6053-T61, 6061-T6, 6061-T43, 6061-T31, 7277-T41
2014-T6, 2014-T4, 2024-T4, 7075-T6	2117-T3, 2017-T31, 2024-T31, 6061-T43, 7277-T41

This discussion of the strength of rivets has dealt exclusively with the question of ultimate strength. The problem of yielding is not encountered in design of rivets. Any shear yielding of rivets is imperceptible as far as the over-all behavior of the connection is concerned.

The effect of repeated loads on the design of riveted connections has been discussed in a preceding section of the handbook, (see pages 107 to 110). For practical design purposes the influence of repeated loads on riveted connections can be considered to be confined entirely to the effect of the rivets and rivet holes on the fatigue strength of the plate or shape. Shear fatigue failures of rivets are extremely rare. Tests show that the fatigue fractures encountered in any normal riveted connection will be in the plates or shapes of the connection, usually through the rivet holes, and that the rivets themselves will remain intact.

Under axial static tensile loading, aluminum alloy rivets will develop tensile strengths about 40 to 60 per cent higher than their static shear strengths. In spite of this fact, however, aluminum alloy rivets are not recommended for carrying tensile loading. Often the loadings are eccentrically applied to the rivets and are of fluctuating intensity so that early fatigue failures tend to develop in the rivets. Bolts are better suited to carrying fluctuating axial tensile loading than rivets.

TABLE 27

Load, in Kips, Required to Produce Failure of One Rivet in Single Shear

Based on average ultimate shear strengths given in Table 26 and single-shear areas given in Tables 25a and 25b.

Size of Rivet, In.	Cold-driven								Hot-driven	
	1100-F	2017-T3	2017-T31	2024-T31	2117-T3	6053-T61	6061-T31	6061-T6	6061-T43 (990°-1050°F)	7277-T41 (850°-975°F)
1/8	0.143	0.505	0.441	0.544	0.428	0.298	0.311	0.389	.....	.....
5/32	0.218	0.775	0.675	0.834	0.655	0.457	0.477	0.596	.....	.....
3/16	0.315	1.12	0.974	1.20	0.945	0.659	0.688	0.860	.....	.....
1/4	0.571	2.02	1.76	2.18	1.71	1.19	1.24	1.56	.....	.....
5/16	0.901	3.20	2.79	3.44	2.70	1.88	1.97	2.46	.....	.....
3/8	1.29	....	3.98	....	3.86	2.69	2.81	3.51	2.97	.....
7/16	1.77	....	5.48	....	5.32	3.71	3.87	4.84	4.15	.....
1/2	2.30	....	7.11	....	6.90	4.81	5.02	6.27	5.32	8.42
9/16	2.89	....	8.92	....	8.66	6.04	6.30	7.87	6.65	10.50
5/8	3.55	....	11.00	....	10.70	7.42	7.74	9.68	8.11	12.80
3/4	5.07	....	15.70	....	15.20	10.60	11.10	13.80	11.50	18.20
7/8	6.86	....	....	....	20.60	14.30	15.00	18.70	16.00	25.40
1	8.92	....	....	....	26.80	18.60	19.50	24.30	21.30	33.70

TABLE 28

Reduction in Shear Strength of Aluminum Alloy Rivets Resulting from Their Use in Thin Plates and Shapes

t_1 = thickness of thinner outside plate, in.
t_2 = thickness of inside plate, in.
D = rivet diameter, in.

Ratio D/t_1	Per Cent Loss in Shear Strength①	Ratio D/t_2	Per Cent Loss in Shear Strength①	Ratio D/t_2	Per Cent Loss in Shear Strength①
3.0	0.0	1.5	0.0	2.8	16.9
3.1	0.4	1.6	1.3	2.9	18.2
3.2	0.8	1.7	2.6	3.0	19.5
3.3	1.2	1.8	3.9	3.1	20.8
3.4	1.6	1.9	5.2	3.2	22.1
3.5	2.0	2.0	6.5	3.3	23.4
3.6	2.4	2.1	7.8	3.4	24.7
3.7	2.8	2.2	9.1	3.5	26.0
3.8	3.2	2.3	10.4	3.6	27.3
3.9	3.6	2.4	11.7	3.7	28.6
4.0	4.0	2.5	13.0	3.8	29.9
...	...	2.6	14.3	3.9	31.2
...	...	2.7	15.6	4.0	32.5

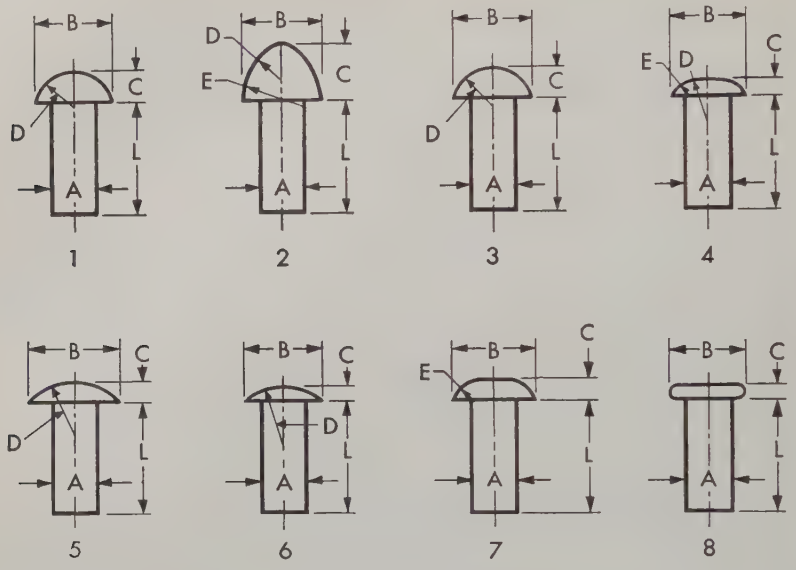
①For double-shear joints, use per cent loss in shear strength corresponding to either D/t_1 or D/t_2, whichever gives the greater loss.

It has already been pointed out that the bearing ultimate strengths and bearing yield strengths of aluminum alloy products listed in Table 4, pages 42 through 66, are applicable only when the distance from the center of a rivet to the edge of the plate or shape, measured in the direction in which the pressure of the rivet is directed, is at least twice the rivet diameter. If a smaller edge distance is employed, the bearing ultimate strength and bearing yield strength must be reduced an appropriate amount. When the edge distance is reduced to one and one-half times the rivet diameter, for example, the bearing ultimate strengths shown in Table 4, pages 42 through 66, must be reduced 22 per cent. The corresponding reduction in bearing yield strength is 15 per cent.

Example 26. Determine the factor of safety against failure for the riveted end connections of the 6061-T6 tension hanger in Example 1, page 95.

TABLE 29

Common Types of Heads Supplied on Aluminum Alloy Rivets

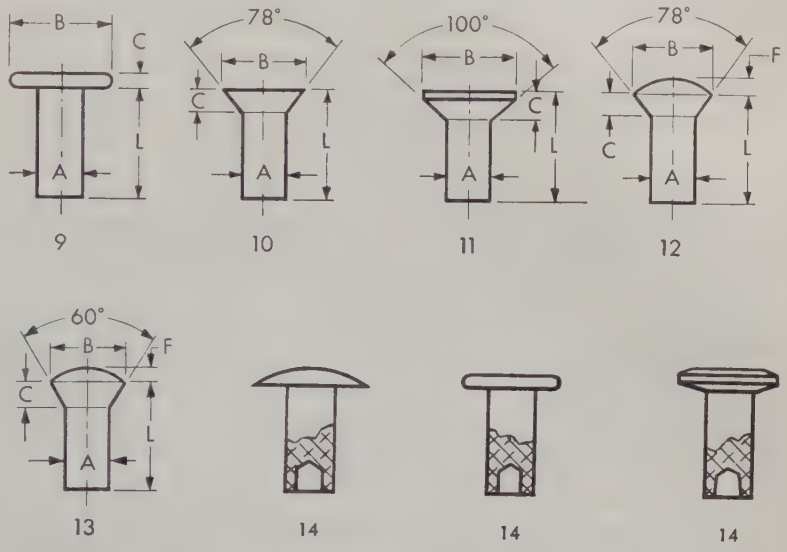


Kind	Military Specifications		Head Diameter B	Head Depth C	Head Radius D	Edge Radius E
	MIL-R-1150A	MIL-R-5674A				
1. Standard Button Head	Type 6 or B-1	.....	1.75A	0.75A	0.885A	.....
①2. High Button Head	Type B-2	.....	1.50A+ 0.031″	0.75A+ 0.125″	0.75A− 0.281″	0.75A+ 0.281″
3. Round Head	Type 3	AN430②	2A	0.75A	1.042A	.....
4. Mushroom Head	Type 5	.....	2A	0.625A	1.634A	0.50A
5. Standard Brazier Head	Type 2	AN455②	2.50A	0.50A	1.8125A	.....
6. Modified Brazier Head	.....	AN456	See Drawing AN456			
7. Universal Head	.....	AN470	2A	0.43A	.....	0.875A
8. Flat Head	Type 4	AN442②	2A	0.40A	.....	.....

①Acorn type, American Standard. Supplied in sizes ½ in. and larger.
②Inactive for design 3-30-48—Use AN470.

TABLE
29

Common Types of Heads Supplied on Aluminum Alloy Rivets—*Concluded*



Kind	Military Specifications		Head Diameter B	Head Depth C	Head Radius D	Oval Depth F
	MIL-R-1150A	MIL-R-5674A				
9. Tinners' Rivets	.....	.....	2.25A	0.30A	.....	.....
10. 78° Flat Ctsk. Head	Type 7	.....	1.81A	0.50A	.....	.....
11. 100° Flat Ctsk. Head	Type 9	AN426	See Drawing AN426			
12. 78° Oval Ctsk. Head	Type 8	.....	1.81A	0.50A	1.7656A	0.25A
③13. 60° Oval Ctsk. Head	Type C-2	.....	1.577A	0.50A	.....	0.187A
14. Tubular Shank, Types	Drawing shows 3 styles. See AN450 and Section BC2A Aluminum Rivet Product Data for Dimensions.					

③Supplied in sizes ½ in. and larger.

To determine the factor of safety against failure of the rivets, both the shear strength of the rivet and the bearing strength of the channel webs must be checked.

The basic single shear strength for one ¾-in. 7277-T41 rivet taken from Table 27, page 168, is 18 2 kips and the corresponding double shear value for the eight-rivet connection is

$$(2 \times 18.2) \times 8 = 291 \text{ kips.}$$

The ratio of rivet diameter to thickness, t_2, of the gusset plate (see sketch, Table 28, page 169) is

$$\frac{D}{t_2} = \frac{0.75}{0.5} = 1.5$$

Table 28 indicates no reduction in shear strength for this value of D/t_2.

The ratio of rivet diameter to thickness, t_1, of the channel web is (see sketch, Table 28)

$$\frac{D}{t_1} = \frac{0.75}{0.225} = 3.33$$

From Table 28, the reduction in shear strength for a rivet with a D/t_1 value of 3.33 is 1.3 per cent. Therefore the actual shear strength of the connection is

$$(1 - 0.013) \times 291 = 287 \text{ kips.}$$

The factor of safety against shear failure is $\frac{287}{70} = 4.10$.

The bearing area for the channel webs (hole diameter taken from Table 25, pages 164 and 165) is

$$2 \times 0.781 \times 0.225 = 0.3515 \text{ sq in.}$$

Assuming that the edge distance is not less than twice the hole diameter, the ultimate bearing strength of the webs from Table 4c, page 52, is 80 kips per sq in.

The load required to produce bearing failure in the connection is

$$80 \times 0.3515 \times 8 = 225 \text{ kips.}$$

The factor of safety against bearing failure is $\frac{225}{70} = 3.21$.

Since the bearing value is less than that for double shear, the factor of safety against failure of the rivets is 3.21.

Note: If the edge distance in the direction of the application of load had been one and one-half times the hole diameter instead of twice the hole diameter, the ultimate bearing strength of the plate would have been reduced 22 per cent so that instead of being 225 kips, it would have been 176 kips. The factor of safety against failure of the rivets would have been 2.51.

The size and spacing of rivets are sometimes dictated by factors other than calculated strength. The following are some general rules that may be helpful in proportioning riveted joints and connections:

1. The diameter of a rivet should not be larger than three times the thickness of the outside plates or shapes and should not be smaller than the thickness of the thickest plate in which the rivet is driven.

2. A rivet used in the leg of an angle should have a diameter not exceeding about 0.3 the width of the leg.

3. The minimum spacing of rivets should be three times the nominal rivet diameter. The maximum spacing is often governed by the possibility of compression buckling of component parts between rivets. Where buckling or strength requirements do not control, the spacing should still be held below some reasonable maximum limit, such as 24 times the thickness of the sheet or plate.

4. In riveted joints that must be made pressure tight by calking the edge of the plates, the edge distance should not exceed one and one-half times the rivet diameter or about four times the thickness of the plate. Spacing of rivets should not exceed four times the rivet diameter nor about ten times the thickness of the plate.

Countersunk aluminum alloy rivets are available with 60-degree heads, 78-degree heads or 100-degree heads. These angles refer to the included angle of the countersunk head as indicated in Table 29, page 170. The driven heads can also be countersunk by properly preparing the hole and then upsetting the shank end of the rivet to fill the countersunk depression. In the latter instance it is always well to provide extra shank material because the pressure required to properly upset the shank of the rivet is reduced if there is material left standing above the surface. This material left standing may be later removed by a chipping or grinding operation if it is desired to have a smooth surface.

In calculating the strength of countersunk rivets, the rules are the same as those applied to protruding head rivets except that in calculating the bearing area some provision must be made for the fact that a countersunk head will not provide fully effective bearing area. A common rule is to deduct half the depth of the countersink from the plate thickness to obtain the thickness effective in bearing. It is preferable that the countersink should not extend completely through the thickness of any part. The sharp edge cutting into the rivet is harmful both to the shear strength of the rivet and to the bearing resistance of the plate or shape.

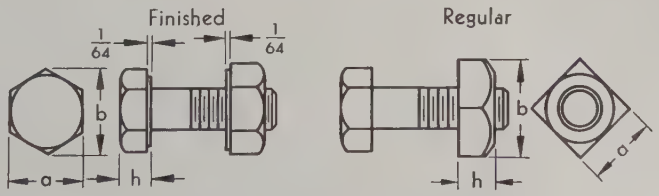
For further information on riveting, the reader is referred to the booklet *Riveting Alcoa Aluminum*.

Bolted Connections

Steel or aluminum alloy bolts may be used in making connections in aluminum alloy parts. For best results the bolts should be fitted tightly in the holes, preferably with a slight interference. Where this is not practicable, the bolts may be used with whatever hole clearance seems suitable to the class of work under consideration, but where bolts are not tightly fitted it is common practice to use less than the full strength of the bolt in calculating the number of bolts

TABLE 30

Nominal Dimensions of Machine Bolts[1] and Nuts



All Dimensions in Inches

Diameter of Bolt	Threads per In.[2]	Shank			Bolt Head[4]						Nut[4]					
		Diameter at Root of Thread	Gross Area in Shank	Area at Root of Thread	Finished Hexagon			Regular and Economy[3] Hexagon			Finished Hexagon			Regular Square		
		In.	Sq In.	Sq In.	a	b	h	a	b	h	a	b	h	a	b	h
1/4[3]	20	0.1887	0.049	0.028	7/16	0.51	5/32	7/16	0.51	11/64	7/16	0.51	7/32	7/16	0.62	7/32
5/16[3]	18	0.2443	0.077	0.047	1/2	0.58	13/64	1/2	0.58	7/32	1/2	0.58	17/64	9/16	0.80	17/64
3/8[3]	16	0.2983	0.110	0.070	9/16	0.65	15/64	9/16	0.65	1/4	9/16	0.65	21/64	5/8	0.88	21/64
7/16	14	0.3499	0.150	0.096	5/8	0.72	9/32	5/8	0.72	19/64	11/16	0.79	3/8	3/4	1.06	3/8
1/2[3]	13	0.4056	0.196	0.129	3/4	0.87	5/16	3/4	0.87	11/32	3/4	0.87	7/16	13/16	1.15	7/16
9/16	12	0.4603	0.249	0.166	13/16	0.94	23/64	....	....	....	7/8	1.01	31/64	....	....	....
5/8[3]	11	0.5135	0.307	0.207	15/16	1.08	25/64	15/16	1.08	27/64	15/16	1.08	35/64	1	1.41	35/64
3/4[3]	10	0.6273	0.442	0.309	1 1/8	1.30	15/32	1 1/8	1.30	1/2	1 1/8	1.30	41/64	1 1/8	1.59	21/32
7/8	9	0.7387	0.601	0.429	1 5/16	1.52	35/64	1 5/16	1.52	37/64	1 5/16	1.52	3/4	1 5/16	1.86	49/64
1	8	0.8466	0.785	0.563	1 1/2	1.73	39/64	1 1/2	1.73	43/64	1 1/2	1.73	55/64	1 1/2	2.12	7/8

[1] Other screw machine products are available in a wide range of sizes. Consult a local Alcoa sales office.
[2] Coarse Threads, Class 2A and 2B. Fine threads can be furnished on special order.
[3] Alcoa Economy (special hexagon head) Bolts are available in the noted sizes.
[4] Dimensions comply with ASA Specification B18.2—1955.

required. A common rule is to use two-thirds of the full strength when bolts are used with more than a few thousands of an inch clearance in the holes. This rule applies both to the bearing strength and to the shearing strength of the bolts.

The principal aluminum alloy used for bolts is 2024-T4, which has the following minimum properties: tensile strength, 62 kips per sq in., tensile yield strength, 40 kips per sq in., ultimate shear strength, 37 kips per sq in. For design purposes the breaking strength of a 2024-T4 bolt in static axial tension may be calculated by multiplying the net area at the root of the thread by the minimum tensile strength. The shear strength of a bolt may be calculated by multiplying the shear area by the shear strength of the material, taking into account any reduction in shear strength indicated in Table 28, page 169. In a properly designed bolt the threads do not extend into the shear area, and the full shank area shown in Table 30, page 174, may be used.

Bolts function best when properly tightened. Unfortunately no definite rules for determining the magnitude of the tightening torque can be laid down since test results vary widely, depending upon the friction developed in the threads and other bearing surfaces, which in turn is greatly influenced by the degree of lubrication, accidental or intentional. One recommendation that is sometimes made with regard to tightening aluminum alloy bolts is as follows: Tighten several bolts of any given size and type to the breaking point under the same conditions of lubrication as will be encountered on the job and then use 70 per cent or 80 per cent of the lowest torque obtained in these tests for tightening all bolts of this size and type on the job. The 70 per cent value should be used for "temporary" bolts, or those that may need to be removed occasionally, while the 80 per cent value applies to "permanent" bolts. The use of a good lubricant on the threads and all bearing surfaces is recommended. A lubricant having a white lead base, prepared for threaded fittings and meeting the requirements of Military Specification JAN-A-669 will give excellent results both as a lubricant and as a protective coating on the contacting surfaces.

The recommendations just given for tightening aluminum alloy bolts are profitably modified for bolts or other threaded parts that carry fluctuating axial tensile loads likely to produce fatigue action. Under these conditions, the optimum tightness (initial axial tensile load) is slig ıtly more (about 5 per cent) than that which is just overcome by the maximum tensile load on the bolt in service.

Nuts to be used on aluminum alloy bolts are generally made of

alloy 2024-T4. Nuts of 6061-T6 alloy are also available and have adequate strength to develop the full strength of 2024-T4 bolts. Nuts made of 6061-T6 alloy are preferred where corrosive conditions are likely to be important.

Aluminum alloy bolts and nuts come in several different finishes and types. The nearest sales office of Aluminum Company of America should be consulted concerning the best type of finish to be used on any particular job.

Special Fasteners

The possibility of making connections with various types of special fasteners should not be overlooked. Most of these special fasteners are of a proprietary nature. Often it will be found desirable to use a connector that can be applied from one side of the work or "driven" from one side of the work even though the fastener itself must be inserted from the back side. A number of excellent "blind" fasteners are made of aluminum alloy for this type of construction and will give excellent service.

Welded Connections

Welding has long been used as a means of making connections in the lower-strength aluminum alloys, particularly where fluid-tight joints are essential as in the pressure-vessel field. Newer methods of welding, specifically the argon-shielded tungsten-arc method and the automatic and semi-automatic argon-shielded consumable-electrode methods, are extending the usefulness and popularity of welded construction to include some of the higher-strength alloys. Only these newer methods will be considered here. Because of the rapid strides being made in the development of new alloys and welding techniques, however, the user should consult the nearest sales office of Aluminum Company of America for the latest information on developments in the field of welding aluminum alloys.

The weldability of aluminum alloys varies considerably. Information regarding weldability of the various alloys is given in Tables 1a and 1b, pages 26 to 32, of this handbook. Only those alloys rated A or B for weldability will be considered here.

From the standpoint of weight, appearance and resistance to repeated loadings, butt welds are the most effective type. When butt welds are made in aluminum alloys in their annealed condition, they usually exhibit 100 per cent efficiency; that is, the joint is at least as strong as the parent metal. When butt welds are made in aluminum alloys in their cold-worked or heat-treated tempers, however, the

heat of welding softens the metal on each side of the weld so that it is not as strong as the original parent metal. Butt welds in the non-heat-treatable alloys have approximately the strength of annealed material, even though the welded parts may have been cold worked prior to welding. The strengths of butt welds in heat-treated material are usually intermediate between the strength of the original parent metal and the strength of the fully annealed material. Table 31, page 178, shows the static tensile strengths of butt welds in various aluminum alloys.

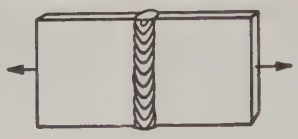
The yield strength across butt welds made in cold-worked or heat-treated aluminum alloys depends on the gage length used, the yield strength increasing with gage length. The yield strength value determined at 0.2 per cent offset on a 10-in. gage length is considered to be applicable to the design of welded structures. The minimum expected value for the 10-in. gage length yield strength across butt welds in 6061-T6 is about 15 ksi.

The strength of the heat-affected material in the vicinity of a weld has a minimum value in a narrow zone adjacent to the weld. Outside this zone, the strength increases until it reaches the strength of the unheat-affected parent metal at a distance from the weld not exceeding 3 inches, for welds made by the tungsten arc or consumable electrode process. If part of the cross section of a welded member is not affected by the heat of welding, as is frequently the case for longitudinally welded members, the material adjacent to the weld is reinforced by the higher strength, unheat-affected material at a greater distance from the weld. The tensile strength of such a part can be calculated as the weighted average of the tensile strength of the material in a zone adjacent to the weld and the tensile strength of the material outside this zone (see Example 27, page 179). For this purpose, the material should be considered to have the strength shown in Table 31, page 178, within a zone extending for a distance of 1½ inches from the weld, and the material outside this region should be considered to have parent metal properties. The 1½ inch reduced-strength zone is measured from the centerline of the weld for butt welds and from the heel of the fillet for fillet welds.

The 3-inch distance from the weld mentioned at the beginning of the preceding paragraph is the distance beyond which the heat of welding has no effect on mechanical properties, whereas the 1½-inch distance used in the calculations defines a zone such that conservative values of strength of welded members can be obtained by assuming the mechanical properties to be a minimum within this zone and equal to the unheat-affected values outside it.

TABLE 31

Strength and Ductility of Welded Butt Joints



Alloy		Tensile Strength Across Weld, Kips per Sq In.		Average Free-Bend Elongation,② Per Cent
Parent Material	Filler Wire	Minimum①	Average②	
Nonheat-treatable Alloys				
1060	1060	9.5	10.0	63
1100	1100	11.0	13.5	54
3003	1100	14.0	16.0	58
3004	3004	23.0	27.5	26
5052	5052	25.0	28.0	39
5086	5356	35.0	39.0	38
5154	5154	30.0	34.0	39
5454	5554	31.0	35.0	40
5456	5556	42.0	46.0	28
Heat-treatable Alloys (Not Heat Treated After Welding)				
2014-T6	4043	....	34.0	9
6061-T6	4043	24.0	27.0	16
6062-T6	4043	24.0	27.0	16
6063-T5	4043	17.0	20.0	..
6063-T6	4043	17.0	20.0	..
6063-T83	4043	17.0	20.0	..
6063-T831	4043	17.0	20.0	..
6063-T832	4043	17.0	20.0	..
Heat-treatable Alloys (Heat Treated and Aged After Welding)				
2014-T6	4043	....	51.0	5
6061-T6	4043	....	43.0	11
6062-T6	4043	....	43.0	11

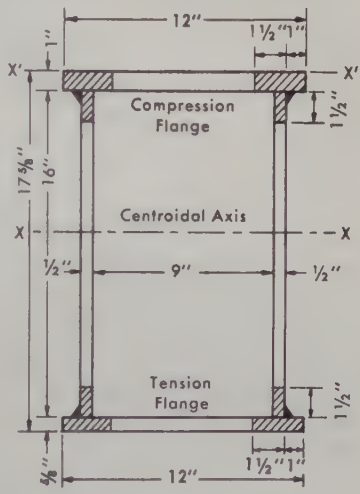
①Minimum strength is considered to be minimum tensile strength of annealed material for nonheat-treatable alloys. For heat-treatable alloys, minimum strength value is based on qualification test requirements of ASME Boiler and Pressure Vessel Code, Section IX, Part B, 1956.

②Based on results of tests of joints made by the argon-shielded tungsten-arc or the argon-shielded consumable electrode method.

The foregoing procedure can also be used to calculate the yield strength of welded parts. For welds parallel to the direction of stress in nonheat-treatable alloys, the yield strength within 1½-in. of the weld is considered to be the yield strength of annealed material. For heat-treatable alloys, the yield strength in the vicinity of a longitudinally stressed weld is usually intermediate between the yield strength of the original parent metal and that of the fully annealed material. The expected minimum yield strength of material adjacent to the weld in 6061-T6, in the direction parallel to the weld, is about 11 ksi. For welds transverse to the direction of stress, the yield strength value that applies in the reduced-strength zone within 1½-in. of the weld is the yield strength measured on a 10-in. gage length across a butt weld.

Example 27. Check the bending stresses in the tension flange of the welded 5456-H321 box beam shown in the sketch, for a bending moment of 2,400 in.-kips. Determine the factor of safety against yielding.

For checking bending stresses in this longitudinally welded member, the reduced-strength zone can be considered as extending 1½ in. from the heels of the fillet welds and thus is represented by the shaded areas in the sketch.



Section Elements (See Table 54, pages 236—261)

Section	Weight Lb/Ft	Area Sq In.	For Axis X'			
			y In.	Ay In.³	Ay² In.⁴	I_o In.⁴
Top Flange	14.11	12.00	0.50	6.0	3	1
2 Webs	18.82	16.00	9.00	144.0	1296	341
Bottom Flange	8.82	7.50	17.31	129.8	2247	0
		35.50		279.8	3,546	342

$$\bar{y}=\frac{\Sigma Ay}{A}=\frac{279.8}{35.5}=7.88 \text{ in.}$$

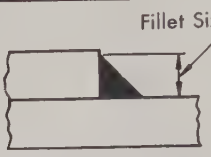
$$c=17.62-7.88=9.74 \text{ in.}$$

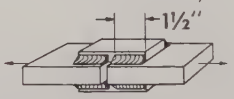
$$I_x=\Sigma I_o+\Sigma Ay^2-\bar{y}\,\Sigma Ay=342+3,546-7.88\times279.8=1,683 \text{ in.}^4$$

$$S \text{ (tension flange)}=\frac{1,683}{9.74}=173 \text{ in.}^3$$

TABLE 32

Shear Strength of Fillet Welds[1]



Alloy of Filler Wire	Average Longitudinal Shear Strength, Kips per Lineal In. of Weld (Ends of Weld Machined)	Average Transverse Shear Strength, Kips per Lineal In. of Weld
	 Test Specimen	Test Specimen
1100	8 F	9 F
4043	11 F	15 F
5154 and 5554	13 F	18 F
5356	16 F	24 F
5556	19 F	30 F

[1]Summary of results of tests of joints with fillet sizes up to ¾ in. made by the argon-shielded tungsten-arc or the argon-shielded consumable electrode method.

For the purpose of computing the "average" yield strength of the tension flange, consider the outermost one-third of the part of the web that lies on the tension side of the neutral axis as being included in the tension flange area.

Gross area of tension flange, A:

Area of plate $12 \times \frac{5}{8} = 7.5$ in.²

One-third of tension area of webs $2 \times (9.74 - 0.62) \times \frac{1}{3} \times \frac{1}{2} = 3.0$ in.²

10.5 in.²

Reduced-strength area of tension flange, A_w:

In flange $2 \times 2\frac{1}{2} \times \frac{5}{8} = 3.1$ in.²

In webs $2 \times 1\frac{1}{2} \times \frac{1}{2} = 1.5$ in.²

4.6 in.²

Minimum mechanical properties of 5456 plate (Table 4a, page 48):

Tensile yield strength of 5456-O = 19.0 ksi.

Tensile yield strength of 5456-H321 = 33.0 ksi.

$$\text{Average tensile yield strength} = \frac{19A_w + 33\ (A - A_w)}{A}$$

$$= \frac{19 \times 4.6 + 33 \times 5.9}{10.5} = 26.9 \text{ ksi.}$$

The maximum stress in the tension flange:

$$f = \frac{M}{S} = \frac{2,400}{173} = 13.9 \text{ ksi.}$$

The factor of safety on yielding is $\frac{26.9}{13.9} = 1.94$

Welded assemblies are sometimes of such size and shape that they can be reheat treated after welding, assuming they are built of a heat-treatable material. This procedure greatly increases the strength of the welded material, but results in some sacrifice in ductility of the weld. Another disadvantage is the warping which often accompanies the heat-treating procedure.

Fillet welds, as well as butt welds, are used in aluminum alloy construction and Table 32, page 180, gives a summary of some results of shear tests of fillet welds. The strength of fillet welds is controlled by the filler wire when the usual combinations of parent metal and filler wire are used. Combinations of parent metal and filler wire that are customarily employed are indicated in Table 31, page 178. If a weaker material were joined by a given filler wire, the strength of fillet welds might be appreciably less than the values given in Table 32.

STORAGE VESSELS, PRESSURE VESSELS, PIPE AND TUBE

Aluminum alloys are widely used for storage vessels, pressure vessels, pipe and tube because they are highly resistant to corrosion when exposed to many liquids that adversely affect, or are adversely affected by, other metals. Some of the liquids for which aluminum alloy construction is well suited are as follows: nitric acid in concentrations of 82 per cent by weight or greater, acetic acid and other organic acids, alcohols, aldehydes, ammonium nitrate, esters, glycerin, highly purified water, hydrogen peroxide, hydrocyanic acid, ketones, nitroparaffins, organic acid anhydrides, petroleum products, vegetable oils and many food and paint products. The fact that aluminum alloys show no tendency toward low-temperature embrittlement (tests have been made at temperatures as low as —423° F) makes them particularly attractive for subzero processes. The nonsparking characteristics make aluminum alloys useful in systems in which inflammable liquids and gases are used.

For pressure vessels under either internal or external pressure, the rules of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers may be used in conjunction with the statutory and regulatory requirements that may affect the use of the vessel. The allowable stress values and design charts in the ASME Code were prepared so as to provide a factor of safety of at least 4 against burst or collapse and a factor of safety of at least 1.5 against excessive deformations by yielding. Creep at elevated temperatures was also taken into account. The alloy designations in this Code are those used by the American Society for Testing

TABLE 33

Min. Permissible $\frac{t}{R}$ Values for Unfired Pressure Vessels

For Cylindrical Shells Designed in Accordance with Par. UG-27(c) of the 1952 Edition of the ASME Boiler and Pressure Vessel Code, Section VIII

$$\frac{t}{R}=\frac{P}{SE-0.6P}$$

t = minimum thickness, in.

R = inside radius, in.

P = design or maximum allowable internal working pressure, psi

S = allowable stress, psi (Note that the units in this formula are psi rather than kips per sq in. in order to be consistent with the ASME Boiler and Pressure Vessel Code.)

E = efficiency of longitudinal joint, taken as 0.8 for welded construction

P	Values of t/R for Operating Temperatures not Exceeding						
	100°F	150°F	200°F	250°F	300°F	350°F	400°F
Alloy 996A-O (1160-O)							
5	0.0038	0.0038	0.0039	0.0043	0.0050	0.0052	0.0060
10	0.0076	0.0076	0.0079	0.0087	0.0101	0.0105	0.0120
15	0.0114	0.0114	0.0118	0.0130	0.0151	0.0158	0.0181
20	0.0153	0.0153	0.0158	0.0174	0.0202	0.0211	0.0242
25	0.0192	0.0192	0.0198	0.0218	0.0254	0.0265	0.0303
30	0.0230	0.0230	0.0238	0.0263	0.0306	0.0319	0.0365
35	0.0269	0.0269	0.0278	0.0307	0.0358	0.0373	0.0427
40	0.0309	0.0309	0.0319	0.0352	0.0410	0.0427	0.0490
50	0.0388	0.0388	0.0400	0.0443	0.0516	0.0538	0.0617
60	0.0467	0.0467	0.0482	0.0534	0.0622	0.0649	0.0746
70	0.0548	0.0548	0.0565	0.0626	0.0731	0.0763	0.0877
80	0.0629	0.0629	0.0649	0.0719	0.0840	0.0877	0.1010
90	0.0711	0.0711	0.0734	0.0814	0.0951	0.0993	.....
100	0.0794	0.0794	0.0820	0.0909	0.1064	0.1111	.....
Alloy M1A-O (3003-O)							
10	0.0037	0.0040	0.0043	0.0046	0.0052	0.0060	0.0070
20	0.0075	0.0080	0.0087	0.0093	0.0105	0.0120	0.0140
40	0.0151	0.0160	0.0174	0.0187	0.0211	0.0242	0.0283
60	0.0227	0.0242	0.0263	0.0283	0.0319	0.0365	0.0427
80	0.0304	0.0324	0.0352	0.0379	0.0427	0.0490	0.0575
100	0.0382	0.0407	0.0443	0.0476	0.0538	0.0617	0.0725
120	0.0460	0.0490	0.0534	0.0575	0.0649	0.0746	0.0877
140	0.0539	0.0575	0.0626	0.0674	0.0763	0.0877	0.1032
160	0.0619	0.0660	0.0719	0.0775	0.0877	0.1010	.....
180	0.0700	0.0746	0.0814	0.0877	0.0993	.....	.....
200	0.0781	0.0833	0.0909	0.0980	0.1111	.....	.....
225	0.0884	0.0943	0.1030	0.1111	.....	.....	.....
250	0.0988	0.1055	.....	.....	.....	.....	.....
275	0.1093	.....	.....	.....	.....	.....	.....
Alloy GR20A-O (5052-O)							
50	0.0101	0.0101	0.0101	0.0105	0.0117	0.0136	0.0162
100	0.0202	0.0202	0.0204	0.0211	0.0235	0.0273	0.0327
150	0.0306	0.0306	0.0308	0.0319	0.0355	0.0413	0.0495
200	0.0410	0.0410	0.0413	0.0427	0.0476	0.0556	0.0667
250	0.0516	0.0516	0.0520	0.0538	0.0600	0.0700	0.0842
300	0.0622	0.0622	0.0628	0.0649	0.0725	0.0848	0.1020
350	0.0731	0.0731	0.0737	0.0763	0.0852	0.0997	.....
400	0.0840	0.0840	0.0848	0.0877	0.0980	0.1149	.....
450	0.0951	0.0951	0.0960	0.0993	0.1111	.....	.....
500	0.1064	0.1064	0.1073	0.1111	.....	.....	.....

TABLE 34

Computed Bursting Pressures[1][2][3]—3003-O Tube[4]

(Based on Minimum Properties)

Outside Diameter, In.	Wall Thickness, In.	Bursting Pressure, Psi
1/8	0.020	4390
	0.022	4900
	0.028	6520
	0.032	7700
	0.035	8630
3/16	0.022	3100
	0.028	4050
	0.032	4720
	0.035	5250
	0.049	7900
1/4	0.022	2260
	0.028	2940
	0.032	3410
	0.035	3760
	0.049	5560
	0.058	6810
5/16	0.028	2310
	0.032	2660
	0.035	2940
	0.049	4290
	0.058	5210
3/8	0.022	1470
	0.028	1900
	0.032	2190
	0.035	2410
	0.049	3490
	0.058	4220
	0.065	4800
7/16	0.035	2040
	0.049	2940
	0.065	4030
1/2	0.028	1400
	0.032	1610
	0.035	1770
	0.049	2550
	0.058	3060
	0.065	3470
5/8	0.028	1110
	0.032	1280
	0.035	1400
	0.049	2000
	0.058	2390
	0.065	2710
3/4	0.035	1160
	0.049	1650
	0.058	1970
	0.065	2220
	0.083	2900
7/8	0.035	990
	0.049	1400
	0.058	1670
	0.065	1890
	0.083	2450
1	0.035	860
	0.049	1220
	0.058	1460
	0.065	1640
	0.083	2130
	0.109	2860
1 1/8	0.035	760
	0.049	1080
	0.058	1290
1 1/4	0.035	680
	0.049	970
	0.058	1150
	0.065	1300
	0.083	1670
	0.109	2230
	0.134	2810
1 3/8	0.035	620
	0.049	880
	0.058	1040
1 1/2	0.035	560
	0.049	800
	0.058	960
	0.065	1080
	0.083	1390
	0.094	1580
	0.125	2140
	0.250	4600
1 5/8	0.035	530
	0.049	740
	0.058	880
1 3/4	0.035	490
	0.049	680
	0.058	810
	0.065	910
	0.083	1180
2	0.035	420
	0.049	600
	0.065	800
	0.083	1030
	0.094	1170
2	0.125	1580
	0.250	3320
2 1/4	0.049	530
	0.065	710
	0.083	910
	0.094	1030
	0.125	1390
	0.250	2920
2 1/2	0.035	330
	0.049	480
	0.065	630
	0.083	810
	0.094	930
	0.125	1240
	0.250	2590
2 3/4	0.049	430
	0.065	570
	0.083	740
	0.094	840
	0.125	1120
	0.250	2340
3	0.049	390
	0.065	530
	0.083	680
	0.094	760
	0.125	1030
	0.250	2130
3 1/4	0.049	370
	0.065	490
	0.094	710
	0.125	940
	0.250	1960

See notes on next page.

(Continued on next page)

TABLE 34

Computed Bursting Pressures①②③—3003-O Tube④—*Concluded*

(Based on Minimum Properties)

Outside Diameter, In.	Wall Thickness, In.	Bursting Pressure, Psi	Outside Diameter, In.	Wall Thickness, In.	Bursting Pressure, Psi	Outside Diameter, In.	Wall Thickness, In.	Bursting Pressure, Psi	Outside Diameter, In.	Wall Thickness, In.	Bursting Pressure, Psi
3½	0.049	330	5	0.063	310	7	0.078	270	10	0.188	460
	0.065	450		0.094	450		0.094	320		0.250	610
	0.083	570		0.125	610		0.125	430		0.375	920
	0.094	660		0.250	1240		0.250	880		0.500	1240
	0.125	880		0.375	1910		0.375	1340		0.625	1580
	0.250	1800		0.500	2590		0.500	1800		0.750	1910
4	0.049	300	5½	0.063	270	8	0.094	280	11	0.219	480
	0.063	380		0.094	420		0.125	380		0.250	550
	0.094	570		0.125	550		0.250	760		0.375	840
	0.125	760		0.250	1120		0.375	1170		0.500	1130
	0.250	1580		0.375	1720		0.500	1580		0.625	1420
	0.375	2430		0.500	2340		0.625	2000		0.750	1720
	0.500	3320	6	0.063	250	9	0.125	340	12	0.219	440
4½	0.063	330		0.094	380		0.250	680		0.250	510
	0.094	510		0.125	500		0.375	1030		0.375	770
	0.125	680		0.250	1030		0.500	1390		0.500	1030
	0.250	1390		0.375	1580		0.625	1730		0.625	1300
	0.375	2130		0.500	2130					0.750	1580
	0.500	2920									

①**Bursting Pressures:** Applicable to operating temperatures not exceeding 100°F.

②**Computation:** These computed internal bursting pressures for round tube are based on the nominal dimensions of the tube, with no allowance for the effects of fittings or end connections, using a modification of the formula given in the American Standard Code for Pressure Piping (ASA B31.1—1951). The modification is the addition of a factor K, which takes care of such items as differences in ductility of various alloys and differences between longitudinal and circumferential tensile strengths, thereby improving the agreement between computed values and test results (K=0.85 for 3003-O). The formula is as follows:

$$P = K\frac{2St}{D-0.8t}$$ in which:

S=specified minimum longitudinal tensile strength, psi (for 3003-O, 14,000 psi). Note that the units in this formula are psi rather than kips per sq in. in order to be consistent with the American Standard Code for Pressure Piping.

t=wall thickness, in. D=outside diameter, in.

K=factor relating yield strength (Y) and tensile strength (s)=0.73+0.33 Y/s.

③**Factor of Safety:** When using these computed internal bursting pressures for design, a suitable factor of safety should be applied. A factor of safety of 4 is often used.

④**Conversion Factors:** For conversion factors for other alloys, tempers and temperatures, see Table 35.

TABLE 35

Conversion Factors[1] for Use with Table 34

Alloy and Temper	Extruded or Drawn	Specified[2] Minimum Tensile Strength, Psi	K[2]	Conversion Factors at Various Metal Temperatures								
				100°F and Under	150°F	200°F	250°F	300°F	350°F	400°F	450°F	500°F
1100-O	Drawn	11,000	0.86	0.79	0.75	0.69	0.62	0.55	0.47	0.39	0.30	0.25
1100-H14	Drawn	16,000	1.03	1.38	1.34	1.26	1.15	1.03	0.89	0.67	0.50	0.28
1100-H18	Drawn	22,000	1.03	1.90	1.81	1.68	1.55	1.34	0.82	0.44	0.33	0.27
2014-T4	Extruded	50,000	0.94	3.95	3.78	3.51	3.29	2.10	1.18	0.90	0.73	0.60
2014-T6	Extruded	60,000	1.01	5.09	4.88	4.56	3.86	2.25	1.27	0.97	0.79	0.65
2024-T3	Drawn	64,000	0.97	5.12	4.90	4.70	4.20	3.42	2.72	2.05	1.49	1.03
2024-T4	Extruded	60,000	0.96	4.83	4.80	4.68	4.45	3.08	1.85	1.27	0.99	0.81
3003-O	Drawn	14,000	0.85	1.00	0.91	0.85	0.79	0.70	0.63	0.55	0.47	0.40
3003-H14	Drawn	20,000	1.02	1.71	1.65	1.58	1.47	1.32	1.15	0.97	0.75	0.52
3003-H18	Drawn	27,000	1.03	2.32	2.16	2.01	1.85	1.67	1.38	1.06	0.76	0.52
3004-O	Drawn	23,000	0.86	1.65	1.65	1.65	1.58	1.39	1.18	1.01	0.85	0.70
5050-O	Drawn	18,000	0.86	1.29	1.28	1.27	1.24	1.16	1.04	0.89	....	....
5052-O	Drawn	25,000	0.88	1.83	1.82	1.78	1.70	1.56	1.40	1.21	1.02	0.83
6061-T4	Drawn	30,000	0.93	2.33	2.25	2.18	2.11	2.08	1.92	1.34	0.84	0.51
6061-T6	Drawn	42,000	1.02	3.60	3.51	3.42	3.28	2.74	2.09	1.47	0.91	0.55
6061-T4	Extruded	26,000	0.93	2.02	1.95	1.89	1.83	1.80	1.67	1.16	0.72	0.44
6061-T6	Extruded	38,000	1.02	3.25	3.17	3.09	2.97	2.48	1.89	1.33	0.82	0.50
6063-T42	Extruded	17,000	0.93	1.32	1.31	1.31	1.31	1.30	0.91	0.57	0.39	0.29
6063-T5	Extruded	22,000	0.99	1.82	1.71	1.65	1.55	1.40	0.96	0.60	0.41	0.31
6063-T6	Extruded	30,000	1.02	2.57	2.45	2.33	2.13	1.56	1.00	0.63	0.43	0.33
6063-T83	Drawn	33,000	1.04	2.88	....	....	....	....	....	....	....	....
6063-T831	Drawn	28,000	1.03	2.41	....	....	....	....	....	....	....	....
6063-T832	Drawn	40,000	1.02	3.73	....	....	....	....	....	....	....	....
7075-T6	Extruded	78,000	1.02	6.66	6.31	5.50	3.78	1.96	1.42	1.16	0.98	0.84

[1] **Conversion Factors:** Factors by which values in Table 34 must be multiplied to obtain bursting pressures for other alloys, tempers and temperatures. Example: computed internal bursting pressure of a 1-in. O.D. by 0.065-in. wall 6061-T6 drawn tube at 250°F is 3.08 times 1640 psi = 5050 psi.

[2] Values used in computing bursting pressures for temperatures of 100°F and under. Note that the values of minimum tensile strength are given in psi rather than in kips per sq in. in order to be consistent with the American Standard Code for Pressure Piping.

Materials and are cross-referenced with commercial designations in Table 6, pages 71 and 72. Table 33, page 182, gives ratios of minimum permissible wall thickness to inside radius computed in accordance with the rules and stress values given in the ASME Code for welded circular cylindrical vessels and pipe to operate at various pressures and temperatures. It should be pointed out that greater thickness may be required because of supports, external loads, corrosion, etc.

Example 28. Determine from Table 33, page 182, the minimum permissible thickness of a cylindrical shell of 3003-O plate in a 60-in. diameter unfired pressure vessel operating at a working pressure of 20 psi at 250°F.

The value of t/R from Table 33 is 0.0093. The radius of the shell is 30 in.; therefore the minimum permissible thickness is $30 \times 0.0093 = 0.279$ in.

Table 33, page 182, may also be used to determine head thicknesses acceptable for Code vessels by using the ratios given below. Slightly thinner heads will result from the use of the formulas in paragraph UG-32 of the Code.

Shape of Head	Construction of Head	Ratio $\frac{t_h}{t_s}$ ①
hemispherical	one-piece	0.5
hemispherical	built-up	0.5
ellipsoidal (2 to 1)	one-piece	0.8
ellipsoidal (2 to 1)	built-up	1.0
torispherical②	one-piece	1.42
torispherical②	built-up	1.77

① t_h = thickness of head
t_s = thickness of cylindrical shell (having one or more longitudinal welds, see Table 33, page 182).

② For crown radius equal to diameter of vessel and knuckle radius equal to 6 per cent of crown radius.

Storage tanks usually do not need a factor of safety as great as that required for pressure vessels because the maximum load that can be applied is ordinarily known much more definitely. The general rules of American Petroleum Institute might be followed as to layout and arrangement of parts. The design stresses, however, must be based on the properties of the aluminum alloy under consideration and are often taken as the specified yield strength times a suitable joint efficiency factor. Additional information can be found in API Standard 12G, "API Specification for Welded Aluminum-Alloy Storage Tanks."

Principles of good structural design should be applied to the supports of pressure and storage vessels. Complete circumferential ring

TABLE **36**

Computed Bursting Pressures①②③④— Schedule No. 40⑤ Pipe

(Based on Minimum Properties)

Nominal Pipe Size,⑥ In.	Bursting Pressures for Various Alloys and Tempers, Psi			
	3003-F	3003-H18	6061-T6	6063-T6
⅛	.....	10,740	16,670	11,900
¼	.....	10,380	16,110	11,490
⅜	.....	8,370	12,990	9,270
½	.....	8,020	12,450	8,880
¾	.....	6,520	10,120	7,220
1	2,630	.....	8,560	6,750
1¼	2,160	.....	7,030	5,550
1½	1,940	.....	6,320	4,990
2	1,630	.....	5,320	4,190
2½	1,790	.....	5,820	4,590
3	1,550	.....	5,050	3,980
3½	1,420	.....	4,600	3,630
4	1,320	.....	4,280	3,370
5	1,150	.....	3,750	2,950
6	1,050	.....	3,410	2,680
8 (0.277)	790	.....	2,560	2,020
8	920	.....	2,990	2,360
10 (0.279)	630	.....	2,070	1,630
10 (0.307)	700	.....	2,280	1,790
10	835	.....	2,720	2,140
12 (0.375)	.....	.....	2,340	1,850

①**Bursting Pressures:** Applicable to operating temperatures not exceeding 100°F. Note that these values of bursting pressure are given in psi rather than kips per sq in. in order to be consistent with the American Standard Code for Pressure Piping.

②**Computation:** These computed internal bursting pressures for pipe are based on the nominal dimensions of the pipe, with no allowance for the effects of fittings or end connections, using a modification of the formula given in the American Standard Code for Pressure Piping (ASA B31.1—1951). For the formula refer to Table 34, note ②.

③**Factor of Safety:** When using these computed internal bursting pressures for design, a suitable factor of safety should be applied. A factor of safety of 4 is often used.

④**Conversion Factors:** For conversion factors for elevated temperatures, see Table 38.

⑤**Size:** ASA Schedule No. 40 pipe sizes, excepting where thickness is given. The 8-in. (0.277) and 10-in (0.307) pipe are Schedule No. 30. The 10-in. (0.279) and 12-in. (0.375) pipe have no ASA schedule numbers.

stiffeners are the best means for distributing support reactions and other concentrated loads. Where these are impracticable, saddles with 180° contact are desirable. Saddles with less than 120° contact should not be used. Concrete saddles should be lined with a bituminous material and girder-type saddles of dissimilar materials should be painted. Tanks are sometimes supported on legs of tubes or structural shapes which are attached to the shell for sufficient length to develop the required strength of the connection. Flat-

TABLE 37

Computed Bursting Pressures[1][2][3][4] — 6063-T6 Construction and Irrigation Tube

(Based on Minimum Properties for Extruded 6063-T6)

Nominal Outside Diameter, In.	Nominal Wall Thickness, In.	Bursting Pressure, Psi
2	0.043[5]	1,340
2	0.055[6]	1,720
3	0.043[5]	890
3	0.065[6]	1,350
4	0.047[5]	720
4	0.072[6]	1,120
5	0.052[5]	640
6	0.058[5]	600
6	0.083[6]	860
7	0.064[5]	560
8	0 072[5]	560
8	0.125[6]	970

[1] **Bursting Pressures:** Applicable to operating temperatures not exceeding 100°F. Note that these values of bursting pressure are given in psi rather than kips per sq in. in order to be consistent with the American Standard Code for Pressure Piping.

[2] **Computation:** These computed internal bursting pressures for tube are based on the nominal dimensions of the tube, with no allowance for the effects of fittings or end connections, using a modification of the formula given in the American Standard Code for Pressure Piping (ASA B31.1—1951). For the formula refer to Table 34, note [2].

[3] **Factor of Safety:** When using these computed internal bursting pressures for design, a suitable factor of safety should be applied. A factor of safety of 4 is often used for construction application.

[4] **Conversion Factors:** For conversion factors for elevated temperatures, see Table 38.

[5] Standard Construction Tube and Irrigation Tube.

[6] Heavy-Duty Construction Tube.

bottom tanks might rest on a concrete or sand-fill base provided with proper drainage to avoid entrapment of moisture. It is considered good practice to interpose an impervious membrane such as asphalt-base roofing paper between the tank and base.

Bursting pressures for tube and pipe, having nominal dimensions based on specified properties at temperatures 100°F and under, are given in Tables 34 through 37 starting on page 183. Conversion factors for determining bursting pressures at elevated temperatures are given in Tables 35 and 38, pages 185 and 189. A suitable factor of safety must be used in conjunction with these computed values. No allowance has been made for dimension tolerances and the effect of joints.

Example 29. Determine from Tables 34 and 35, pages 183 and 185, the factor of safety against bursting for a 2-in. O.D. × 0.049-in. wall 6061-T6 drawn tube at 200°F metal temperature, operating at 500 psi internal pressure.

TABLE **38**

Conversion Factors[1] for Use with Tables 36 and 37

Alloy and Temper	Specified Minimum[2] Tensile Strength, Psi	K[2]	Conversion Factors at Various Metal Temperatures								
			100°F and Under	150°F	200°F	250°F	300°F	350°F	400°F	450°F	500°F
3003-F	14,000	0.85	1.00	0.91	0.85	0.79	0.70	0.63	0.55	0.47	0.40
3003-H18	27,000	1.03	1.00	0.93	0.87	0.80	0.72	0.60	0.46	0.33	0.22
6061-T6	38,000	1.02	1.00	0.98	0.95	0.91	0.76	0.58	0.41	0.25	0.15
6063-T5	22,000	0.99	1.00	0.94	0.91	0.85	0.77	0.53	0.33	0.23	0.17
6063-T6	32,000	1.02	1.00	0.95	0.91	0.84	0.61	0.39	0.25	0.17	0.13

[1] **Conversion Factors:** Factors by which values in Tables 36 and 37, must be multiplied to obtain bursting pressures for elevated temperatures. Example: computed internal bursting pressure of a 1-in. Schedule 40, 6063-T6 pipe at 250°F is 0.84 times 6,750 psi = 5,670 psi.

[2] Values used in computing bursting pressures for temperatures of 100°F and under. Note that the values of minimum tensile strength are given in psi rather than in kips per sq in. in order to be consistent with the American Standard Code for Pressure Piping.

From Table 34 the bursting pressure for a 2-in. O.D. × 0.049-in. wall 3003-O tube at room temperature is 600 psi.

From Table 35 the conversion factor for a 6061-T6 drawn tube at 200°F is 3.33.

Therefore the bursting pressure is $600 \times 3.33 = 2000$ psi. The factor of safety against bursting is $2000/500 = 4.0$.

Fittings and attachments are available for aluminum alloy installations. Flanges of the slip-on, welding-neck and lap-joint types, conforming to American Standards Association dimensions, can be readily obtained in 6061-T6 alloy, but other alloys can be used. Those of 6061-T6 construction, when used at room temperature, are rated by the manufacturer for the same pressures allowed on carbon steel flanges.

Welding fittings such as elbows, tees and stub ends are also available in American Standards Association dimensions. These are ordinarily supplied in 3003-F alloy, but other alloys are also used. The manufacturer rates these fittings for the same pressures as pipe of the same alloy to which they are attached. A full line of threaded pipe fittings and flanges cast in B214 alloy is readily available in sizes through 4 in. Bolt-hole dimensions and outside diameter of these flanges conform to those of American Standard 125-lb cast-iron flanges, Manufacturers Standardization Society 150-lb bronze flanges and American Standard 150-lb steel flanges. The fittings conform to Navy specification 45F13a for 125-lb fittings which requires a 60-psi air test or a 250-psi hydrostatic test without leak-

age or sweating. Threads are American Standard taper pipe thread ASA B2.1. Couplings, nipples and plugs in sizes up to and including ½ in. are made of 6061-T6.

The required thickness of aluminum alloy flanges is sometimes reduced by incorporating a steel reinforcing ring behind each of the aluminum flanges. Stainless steel or galvanized steel bolts are often used, especially for connections that must be opened and closed regularly.

Special fittings of the compression or flared type for aluminum tubes are regularly manufactured from 2017, 2024, 2014 and 2011 alloys or combinations of these alloys. Fittings made from 6061-T6 alloy can be used where higher resistance to corrosion is required.

DESIGN CONSIDERATIONS

Limiting Proportions of Members

After a member has been designed for strength considerations, as outlined in the preceding sections of this book, attention should be given to any other factors that might dictate an increase in the size. This is particularly true in the case of members that are very lightly loaded in service and hence might not be sufficiently sturdy to withstand handling in the shop, or accidental loadings which might occur during assembly or in service.

In some fields of design, arbitrary standards have been set up limiting the size of members with respect to slenderness ratio, width-thickness ratio, width-length ratio, etc. When designing in fields where such standards have been set up, it is advisable, of course, to consider how such standards might apply to the aluminum assembly. No general rules can be laid down here for all types of engineering design, but the experienced designer will not completely ignore conventional good practice in these respects.

Latticed Members and Trusses

Latticed members and trusses should be designed as such and not as though they were solid-web members. The deformations of the web members of a truss-like framework are generally large enough to have an appreciable effect on the over-all behavior of the assembly.

It is highly advantageous to have web and chord members in a truss-like frame arranged so that their centroidal axes intersect at a common point at each junction involving three or more members. Where it is not practicable to arrange for this type of intersection, it is well to investigate the secondary stresses induced.

Deflection

The deflections of aluminum alloy members and assemblies can be calculated using the conventional deflection formulas. The value of modulus of elasticity of the material can be obtained from Table 3, pages 35 to 38. Since the aluminum alloys have a lower modulus of elasticity than steel, greater deformations are to be expected at any given stress level. Frequently it will be found that such differences are of no consequence, and each case must be investigated on its merits. Limiting deflections set up primarily for steel structures need not necessarily apply to comparable aluminum alloy structures.

For those cases in which deflection becomes a controlling item in the design, care should always be taken to use the available metal as effectively as possible in the interest of both economy and elimination of needless deadweight. For members under axial tension or compression, the lengthening or shortening over a given length can be decreased only by increasing the area and thus reducing the stress. For members or assemblies in flexure, the deflection can be reduced in two ways: one is to add cross-sectional area, suitably distributed, while holding the depth of the member constant; and the other is to increase the depth with or without additional area. The second method is preferable because it is more economical of material.

The bending deflections of solid-web flexural members can be calculated from the formulas on pages 201 to 205. Another method of calculating bending deflection of such members is to use the following formula which is simply a modification of those shown on the pages just mentioned:

$$D = \frac{fL^2}{KEc} \tag{28}$$

where D = maximum bending deflection, in.,
f = maximum bending stress on the extreme fiber at midspan, kips per sq in.,
L = span length, in.,
K = a constant dependent on loading conditions,
E = the modulus of elasticity of the material, kips per sq in.,
c = the distance from neutral axis to the extreme fiber, in.

Some values of K for simple-span loadings are as follows:

Uniform load over entire span, K = 9.6,
Equal concentrated loads at third points of span, K = 9.4,
Single concentrated load at midspan, K = 12,
Constant bending moment across entire span (uniform curvature), K = 8.

It is interesting to note that there is relatively little variation in the value of K regardless of the type of loading. For preliminary

design of aluminum flexural members, it is often sufficiently accurate to assume a value of KE = 100,000 kips per sq in. in formula (28).

Shearing deflection of solid-web beams and girders is generally so small in comparison to the bending deflection that it can be ignored except in the case of very short, deep beams. For example, if an 8-in. I-beam with a 0.532-in. thick web is loaded with a concentrated load at the center of a simple span, deflection caused by shear strains makes up only 3.5 per cent of the total deflection when the span is ten feet. If the span is four feet, however, shear accounts for 18 per cent of the total deflection, and when the span is reduced to two feet, 47 per cent of the total deflection is caused by shear. In the latter cases, of course, shear deformation should be taken into account in computing the deflection.

When a member is subjected to a constant torque, and the twisting of the member is not affected by restraint of warping (see page 101), the angle through which the member twists is given by the following formula:

$$\phi = \frac{TL}{GJ} \tag{29}$$

where ϕ = angle of twist in length L, radians,
T = torque, in.-kips,
L = length, in.,
G = shear modulus, kips per sq in.,
J = torsion constant in.^{4} (see Tables 15a and 15b, pages 102 and 103).

If the torque varies along the length of the member, the total angle of twist may be found by integration or by adding up increments of twist calculated from the above formula for increments of length over which the torque may be assumed to be constant.

When flanged members are subjected to torsion and certain cross sections are restrained from warping out of their original planes (see page 101), the amount of twist is less than that given by formula (29).

Impact

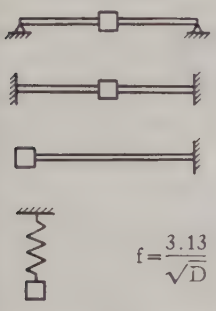
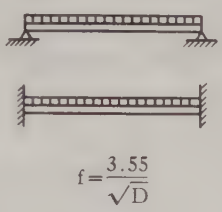
Impact loadings in engineering design problems are often handled simply by applying a suitable impact factor to the corresponding live loads to take account of the dynamic effects. In other words, problems involving dynamic loadings are translated into terms of equivalent static loadings. This procedure is satisfactory only in those cases in which sufficient experience has been accumulated to serve as a guide in selecting the impact factors to be used. In other cases, it may be necessary to calculate the amount of energy in-

TABLE 39

Natural Frequency of Vibration

f = natural frequency of vibration, cycles per second

D = maximum static deflection of member under its own weight plus any weights which vibrate with it, in.

Concentrated Load on Relatively Light Beam or Spring	Uniform Load on Beam Supported at Ends	Uniform Load on Cantilever Beam
 $f = \frac{3.13}{\sqrt{D}}$	 $f = \frac{3.55}{\sqrt{D}}$	$f = \frac{3.89}{\sqrt{D}}$

volved in the impact loading and to estimate the stresses that will result as the structure absorbs this amount of energy. The properties of the aluminum alloys are substantially constant for speeds of loadings ordinarily encountered in engineering design.

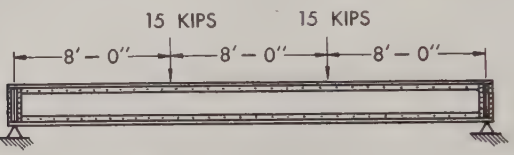
Vibration

It is sometimes necessary to consider possible harmful effects of vibration on members or assemblies. Care should be taken that the natural frequencies of the parts, and of the assembly as a whole, lie outside of a range from ½ to twice the frequency of any regularly repeated impulses. This is necessary because if the natural frequency of a part or assembly should synchronize, or nearly synchronize, with the frequency of some impulse which is repeated, then the deflections of the part or assembly can build up to dangerous proportions and the stresses can be far above those calculated for static loading conditions.

The natural frequency of a member or assembly can be estimated by means of the formulas shown in Table 39, above. In the case of horizontal structural members, the deflection D is calculated in the

ordinary manner, but in the case of members whose position is other than horizontal, the deflection is calculated as though the member were in a horizontal position. This use of the deflection is simply a convenient method of taking into account the stiffness and span length of the member and the magnitude and distribution of the mass that is in motion when the member is vibrating.

Example 30. Determine the natural frequency of vibration of the plate girder in Example 2, page 97, assuming a loading condition as shown in the sketch below. The loads are attached to and vibrate with the girder.



$I = 1430$ in.^{4}

$E = 10{,}000$ kips per sq in.

Dead weight $= 0.01778$ kips per foot $= 0.00148$ kips per inch.

The deflection at the center of the span resulting from the dead weight of the girder is,

$$D_1 = \frac{5wL^4}{384EI} = \frac{5 \times 0.00148 \times (24 \times 12)^4}{384 \times 10{,}000 \times 1430} = 0.01 \text{ in.}$$

The deflection at the center of the span resulting from the applied loads is (see page 202),

$$D_2 = \frac{Pa}{24EI}(3L^2 - 4a^2) = \frac{15\,(8 \times 12)\,[3(24 \times 12)^2 - 4(8 \times 12)^2]}{24 \times 10{,}000 \times 1430} = 0.89 \text{ in.}$$

The total deflection at the center of span is,

$$D = D_1 + D_2 = 0.01 + 0.89 = 0.90 \text{ in.}$$

In Table 39, page 193, the case which most nearly approximates this one is the uniformly loaded beam.

$$f = \frac{3.55}{\sqrt{D}} = \frac{3.55}{\sqrt{0.90}} = 3.74 \text{ cycles per second.}$$

Any regularly repeated impulses to which this beam or girder may be subjected should not come within the range of 1.9 to 7.5 cycles per second.

Transverse Loads on Flat Plates

The stresses and deflections set up in a flat plate panel by a load acting perpendicular to the surface are functions of a number of variables including the proportions of the flat plate panel, the edge conditions, the thickness of the plate, and the distribution of the load. No attempt will be made here to cover all the ramifications of this problem, but for cases in which the plate is of uniform thickness and the deflections are relatively small (less than one-half the thick-

ness of the plate), the following formulas are useful in calculating the bending moment in the plate:

For circular plates with load distributed uniformly over a concentric circular area:

Edges simply supported,

$$M = P\left[\tfrac{1}{4}\log_{10}\frac{D}{D_L} + 0.080 - 0.013\left(\frac{D_L}{D}\right)^2\right] \qquad (30a)$$

Edges fixed,

$$M = P\left[\tfrac{1}{4}\log_{10}\frac{D}{D_L} + 0.027\left(\frac{D_L}{D}\right)^2\right] \qquad (30b)$$

For square plates with load distributed uniformly over a centrally located square area:

Edges simply supported,

$$M = P\left[\tfrac{1}{4}\log_{10}\frac{b}{b_L} + 0.049\right] \qquad (31a)$$

Edges fixed,

$$M = P\left[\tfrac{1}{4}\log_{10}\frac{b}{b_L} - 0.013 + 0.041\left(\frac{b_L}{b}\right)^2\right] \qquad (31b)$$

where M = bending moment at center of plate, in.-kips per in. of width,
P = total load on plate, kips,
D = span (diameter) of circular plate, in.,
D_L = diameter of loaded area on circular plate, in.,
b = span of square plate, in.,
b_L = length of side of loaded area on square plate, in.

The above formulas apply for uniformly distributed loads covering the entire area of the plate, as well as for loads concentrated over a small area. When the load covers the entire area, the ratio D/D_L or b/b_L is equal to 1.0 and its logarithm is zero.

The bending moment at the center of the plate, given by the above formulas, is the maximum bending moment in the plate, except in cases where the edges of the plate are fixed and the load covers all or most of the plate. In such cases, the maximum bending moment in the plate occurs at the edge.[1]

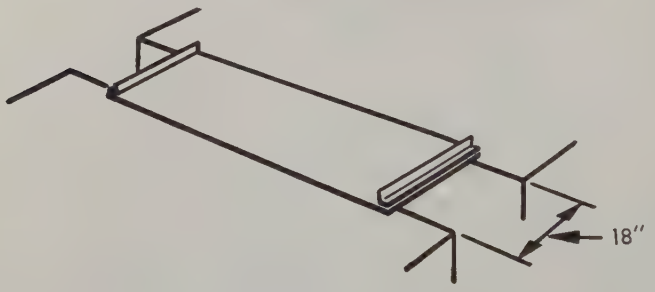
For loads concentrated over a relatively small area, formulas (30a) and (30b) apply approximately to oval plates, and formulas (31a) and (31b) apply approximately to rectangular plates, provided that

[1] See, for example, R. J. Roark, *Formulas for Stress and Strain*, Chapter 10, McGraw-Hill Book Co., Inc., New York, 1943.

D or b is taken to be the smallest span of the plate. The formulas also apply approximately if the concentrated load is anywhere in the vicinity of the center, in which case M is the maximum bending moment under the load rather than at the center of the plate. If the loaded area is not circular or square, the maximum bending moment can be approximated by means of the above formulas if D_L or b_L is assumed to be the dimension of a circle or square having the same area as the actual loaded region.

When simply-supported square plates are subjected to transverse loads, the corners of the plate tend to deflect upward. The question of whether or not the corners are held down has no appreciable effect on the maximum bending moment in the case of concentrated loads but does have some influence if the loads cover all or most of the plate. Formula (31a), page 195, is based on the assumption that the corners are held down.

Example 31. Calculate the factor of safety against yielding for the ⅜-in. thick 6061-T6 aluminum dock plate shown in the sketch when loaded by an industrial truck with a wheel loading of 2 kips. The area of contact of one tire is measured to be 7×4 in.



The loaded area is equivalent to a 5.3-in. square. From formula (31a), page 195,

$$M = P\left[\tfrac{1}{4}\log_{10}\frac{b}{b_L} + 0.049\right] = 2\left[\tfrac{1}{4}\log_{10}\frac{18}{5.3} + 0.049\right] = 0.36 \text{ in.-kips.}$$

Section modulus for a 1-in. wide strip (Table 60, page 271),

$$S = \frac{bd^2}{6} = \frac{1 \times (\tfrac{3}{8})^2}{6} = 0.023 \text{ in.}^3$$

$$\text{Stress} = \frac{M}{S} = \frac{0.36}{0.023} = 16 \text{ kips per sq in.}$$

From Table 4a, page 48, minimum yield strength for 6061-T6 plate is 35 kips per sq in.

$$\text{Factor of safety against yielding} = \frac{35}{16} = 2.2$$

Design of Corrugated Sheet Panels

Corrugated sheet panels are usually designed to withstand uniformly distributed loads such as wind or snow. The stresses and deflections produced in such panels by any such system of loading can be calculated by using the section elements given in Table 59, page 270.

The values of moment of inertia listed in Table 59 were calculated from the following formulas:

For Alcoa Industrial Roofing Sheet,

$$I_x = 0.15\ btd^2 \tag{32a}$$

For Alcoa Farm Roofing Sheet,

$$I_x = 0.13\ btd^2 \tag{32b}$$

where I_x = moment of inertia of the corrugated sheet about axis X-X as shown in Table 59, page 270, for the width under consideration, in.^{4},

b = projected width under consideration, in.,

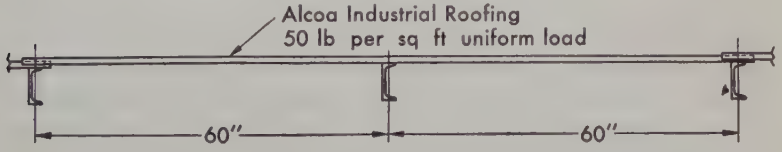
t = thickness of the corrugated sheet, in.,

d = mean depth of the corrugated sheet, in.

The mean depth of the corrugated sheet is found by subtracting the thickness from the over-all depth.

For corrugated shapes of approximately sinusoidal form not covered in Table 59, approximate values of moment of inertia can be calculated from formula (32a) or (32b), the choice of the formula depending on whether the proportions of the corrugations (ratio of pitch to depth) are closer to the proportions of Alcoa Industrial Roofing Sheet or Alcoa Farm Roofing Sheet.

Example 32. Calculate the factor of safety against yielding for the Alcoa Industrial Roofing Sheet shown in the sketch, carrying a uniform load of 50 lb per sq ft. Assume that the yield strength for the sheet is 32 kips per sq in.



The maximum bending moment for a uniformly loaded beam is $wL^2/8$ (at the center) if the ends are simply supported, and $wL^2/12$ (at the ends) if the ends are fixed. Since fasteners for roofing sheet generally provide partial fixation at the ends, assume the maximum bending moment to be $wL^2/10$. Then, for a 12-in. wide strip of sheet,

$$M = \frac{wL^2}{10} = \frac{(0.05/12)\ (60)^2}{10} = 1.50 \text{ in.-kips.}$$

From Table 59, page 270, the section modulus, S_x, for a 12-in. wide strip is 0.0936 in.^{3} The bending stress is

$$f = \frac{M}{S} = \frac{1.50}{0.0936} = 16.0 \text{ kips per sq in.}$$

$$\text{Factor of safety against yielding} = \frac{32.0}{16.0} = 2.0.$$

Extruded Shapes

A relatively small investment in extrusion dies makes it possible to obtain metal in practically any desired shape, which can effect important economies in fabrication and design. Although there are some limitations on thickness and form, it is possible to obtain almost any desired shape that will fit inside a 23-in. diameter circle. The limitations on thickness and form of section differ to some extent depending upon the alloy, but in most alloys thicknesses down to 0.040 inch can be produced in the smaller sections. Hollow extruded shapes are possible in many cases. While the designer should always give preference to standard shapes, for which there is no tool charge, the possibilities of special shapes produced by the extrusion process should not be overlooked. A very modest saving on the material will soon pay off the tool charge. Consultation with the nearest Alcoa sales office will bring further information on this subject.

Castings

The choice of the casting process to be used for a certain application involves both economic and technical considerations. Where the quantity of identical parts is small, the expense of metal molds or dies may not be justified and sand casting is usually used. Sand casting is also necessary where intricate coring is required, although for certain designs and applications the plaster process or investment casting might be used. The dimensional tolerances for sand casting are about $\pm 1/32$ in., and the thinnest sections are generally $3/16$ in. Permanent-mold casting produces a better surface finish and a better metallurgical structure because of the higher rate of solidification. It is also a more rapid means of production for most castings. The tolerances are about $\pm 1/64$ in., and minimum sections are generally $1/8$ in. in thickness. The permanent-mold method may be adapted to produce parts requiring more complex coring by the use of sand cores, thus making it a semipermanent-mold process.

Die-cast sections can be as thin as $1/16$ in. with tolerances as small as ± 0.002 in. The close tolerances and good surface finish of die castings often eliminate costly machining. This process is par-

ticularly adaptable to the production of small castings in large quantities.

Although each casting process possesses certain distinctive design requirements, some features which the design engineer must consider are applicable to all processes. From a foundry standpoint, it is desirable to maintain uniform sections throughout a casting. When it is necessary to use a design in which thin and thick sections join, a gradual increase in thickness of the thinner section toward the junction is advantageous. This blending of sections and provision of generous fillets at ribs and bosses are valuable not only from the standpoint of avoiding shrinkage and cracking, but are useful as well in providing a more desirable stress condition under the action of service loads.

Where bearing or loading conditions indicate the need for bushings or bearing surfaces of harder metals, appropriate inserts can be used. It is essential that lugs, splines or other mechanical means be included in the design of the insert to provide a positive means of load transmission.

Close cooperation between the design engineer and the producing foundry during all stages of planning and design is essential in achieving the optimum combination of casting process, alloy and design details. Additional information can be obtained at the nearest Alcoa sales office.

Forgings

Although the use of light alloy forgings has always been, and still is, chiefly identified with aircraft construction, these products now find important applications in a much broader market. Forged aluminum truck wheels and diesel engine pistons have obtained wide and rapidly growing acceptance. Many small forgings are now used in a variety of applications including textile manufacturing equipment, business machines, small power-driven hand tools, etc., where lightness, strength, appearance and resistance to corrosion are important factors.

Rough hand-forged blocks (blocks forged without the use of cavity dies) are available in most of the forging alloys and are frequently used where the desired part can be machined from such a block. If only a few parts are to be made, it is much more economical to make them in this manner than to purchase the cavity dies which would be required to produce the part more nearly to the final dimensions. No special precautions are required in the design of parts to be machined from hand-forged blocks except to take

account of directional properties and to order such blocks as nearly as possible to the final size of the finished parts. Better properties are obtained by using small blocks suitable for making single parts than by using larger blocks and cutting several parts from a single block.

Where the number of identical parts required is sufficiently large, die forgings are to be preferred over hand-forged blocks. Not only is there a saving in machining costs but better properties are obtained. To develop the best properties in die forgings the designer should consult with the forging producer concerning such matters as provision for proper draft on all projecting parts, minimum thickness, location of parting lines, fillet radii and general configuration. Proper allowance must be made for shrinkage and other tolerances. For additional information the prospective user of aluminum forgings is referred to the nearest Alcoa sales office.

Bearings

Aluminum bearing alloys are currently in use in a variety of engine and machinery applications. The ability of aluminum bearings to carry high bearing loads and their excellent resistance to fatigue and corrosion are often advantageous in high-output mechanical equipment. In current applications these bearings are operating successfully under loads of 5000 psi and even higher. Allowable shaft speeds are dependent to a certain extent upon the nature and intensity of loading, lubrication and the design of the associated machine elements. Positive lubrication must be provided in all cases.

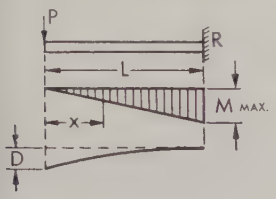
Aluminum alloy bearing materials can be substituted for bearing bronzes in many applications without any design changes. The use of aluminum bearings in place of antifriction bearings or babbitted bearings may require design modifications. Additional information concerning aluminum bearings and assistance with design problems can be obtained through the nearest Alcoa sales office.

Beam Formulas

BENDING MOMENTS AND DEFLECTIONS OF BEAMS

1. CANTILEVER BEAM

Concentrated Load at Free End



Reaction, $R = P$

Moment at any point: $M = Px$

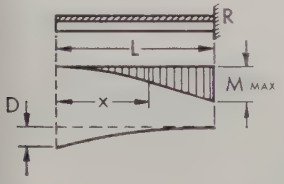
Maximum moment, $M_{max} = PL$

Maximum deflection, $D = \frac{PL^3}{3\,EI}$

---

2. CANTILEVER BEAM

Uniform Load, w per unit of length, total load W



Reaction, $R = wL = W$

Moment at any point: $M = \frac{wx^2}{2} = \frac{Wx^2}{2L}$

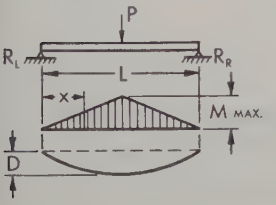
Maximum moment, $M_{max} = \frac{wL^2}{2} = \frac{WL}{2}$

Maximum deflection, $D = \frac{wL^4}{8\,EI} = \frac{WL^3}{8\,EI}$

---

3. SIMPLE BEAM

Concentrated Load at Center



Reactions: $R_L = R_R = \frac{P}{2}$

Moment at any point:

$$x \leqq \frac{L}{2},\ M = \frac{Px}{2}$$

$$x \geqq \frac{L}{2},\ M = \frac{P(L-x)}{2}$$

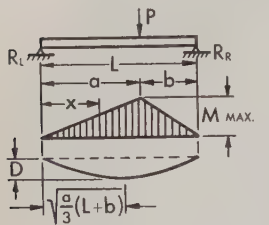
Maximum moment, at center, $M_{max} = \frac{PL}{4}$

Maximum deflection, $D = \frac{PL^3}{48\,EI}$

Continued on next page

4. SIMPLE BEAM

Concentrated Load at any point



Reactions: $R_L=\frac{Pb}{L}$, $R_R=\frac{Pa}{L}$

Moment at any point:

$$x \leqq a,\ M=R_L x=\frac{Pbx}{L}$$

$$x \geqq a,\ M=R_R(L-x)=\frac{Pa(L-x)}{L}$$

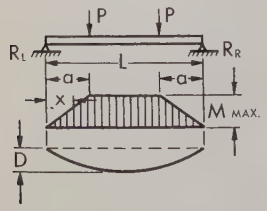
Maximum moment, at $x=a$, $M_{max}=\frac{Pab}{L}$

Maximum deflection, $D=\frac{Pab(L+b)\sqrt{3a(L+b)}}{27\,EIL}$

---

5. SIMPLE BEAM

Two equal, concentrated loads, symmetrically placed



Reactions: $R_L=R_R=P$

Moment at any point:

$$x \leqq a,\ M=R_L x=Px$$

$$a \leqq x \leqq (L-a),\ M=Pa$$

$$x \geqq (L-a),\ M=P(L-x)$$

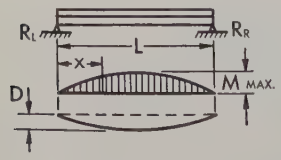
Maximum moment, $M_{max}=Pa$

Maximum deflection, $D=\frac{Pa}{24\,EI}(3L^2-4a^2)$

---

6. SIMPLE BEAM

Uniform Load, w per unit of length, total load W



Reactions: $R_L=R_R=\frac{wL}{2}=\frac{W}{2}$

Moment at any point:

$$M=\frac{wx(L-x)}{2}=\frac{Wx(L-x)}{2L}$$

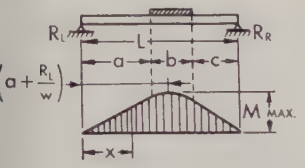
Maximum moment, at center, $M_{max}=\frac{wL^2}{8}=\frac{WL}{8}$

Maximum deflection, $D=\frac{5wL^4}{384\,EI}=\frac{5WL^3}{384\,EI}$

---

7. SIMPLE BEAM

Uniform Load, w per unit of length, on part of span



Reactions: $R_L=\frac{bw(2c+b)}{2L}$, $R_R=\frac{bw(2a+b)}{2L}$

Moment at any point:

$$x \leqq a,\ M=R_Lx=\frac{bwx(2c+b)}{2L}$$

$$a \leqq x \leqq (a+b),\ M=R_Lx-\frac{(x-a)^2w}{2}$$

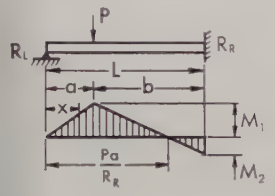
$$x \geqq (a+b),\ M=R_R(L-x)$$

Maximum moment, $M_{max}=R_L\left(a+\frac{R_L}{2w}\right)$

---

8. BEAM FIXED AT ONE END, SIMPLE SUPPORT AT OTHER

Concentrated Load at any point



Reactions: $R_L=\frac{Pb^2}{2L^3}(2L+a)$, $R_R=P-R_L$

Moment at any point:

$$x \leqq a,\ M=R_Lx=\frac{Pb^2x}{2L^3}(2L+a)$$

$$x \geqq a,\ M=R_Lx-P(x-a)$$

Moment at $x=L$, $M_2=\frac{-Pab}{2L^2}(L+a)$

Moment at $x=a$, $M_1=\frac{Pab^2}{2L^3}(2L+a)$

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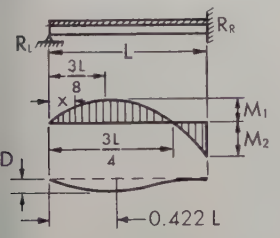
9. BEAM FIXED AT ONE END, SIMPLE SUPPORT AT OTHER

Uniform Load, w per unit of length, total load W



Reactions: $R_L=\frac{3wL}{8}$, $R_R=\frac{5wL}{8}$

Moment at any point:

$$x \leqq L,\ M=wx\left(\frac{3L}{8}-\frac{x}{2}\right)$$

Moment at $x=\frac{3L}{8}$, $M_1=\frac{9wL^2}{128}$

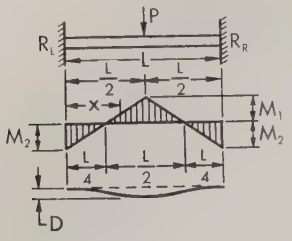
Maximum moment, $x=L$, $M_2=\frac{-wL^2}{8}$

Maximum deflection, $D=0.00542\frac{wL^4}{EI}=0.00542\frac{WL^3}{EI}$

Continued on next page

10. BEAM FIXED AT BOTH ENDS

Concentrated Load at center



Reactions: $R_L = R_R = \frac{P}{2}$

Moment at any point:

$$x \leqq \frac{L}{2},\ M = \frac{-P}{2}\left(\frac{L}{4} - x\right)$$

$$x \geqq \frac{L}{2},\ M = \frac{P}{2}\left(\frac{3L}{4} - x\right)$$

Maximum moment:

$$x = 0 \text{ and } x = L,\ M_2 = \frac{-PL}{8}$$

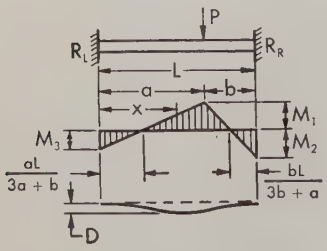
$$x = \frac{L}{2},\ M_1 = \frac{PL}{8}$$

Maximum deflection, $D = \frac{PL^3}{192\ EI}$

---

11. BEAM FIXED AT BOTH ENDS

Concentrated Load at any point



Reactions: $R_L = \frac{Pb^2}{L^3}(L+2a)$, $R_R = \frac{Pa^2}{L^3}(L+2b)$

Moment at any point:

$$x \leqq a,\ M = \frac{-Pab^2}{L^2} + R_L x$$

$$x \geqq a,\ M = \frac{-Pa^2b}{L^2} + R_R(L-x)$$

Moment at x=0, $M_3 = \frac{-Pab^2}{L^2}$

Moment at x=a, $M_1 = \frac{2Pa^2b^2}{L^3}$

Maximum moment, $a \geqq b$, $M_2 = \frac{-Pa^2b}{L^2}$

Maximum deflection, $a \geqq b$, $D = \frac{2Pa^3b^2}{3\ EI\ (3a+b)^2}$

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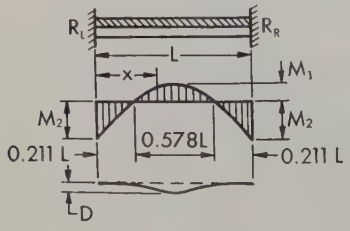
12. BEAM FIXED AT BOTH ENDS

Uniform Load, w per unit of length, total load W



Reactions: $R_L = R_R = \frac{wL}{2} = \frac{W}{2}$

Moment at any point:

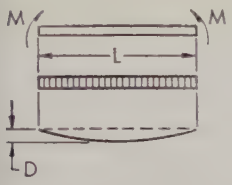
$$x \leqq L,\ M = \frac{-wL^2}{12} - \frac{wx^2}{2} + \frac{wLx}{2}$$

Maximum moment, x=0 and x=L, $M_2 = \frac{-wL^2}{12} = \frac{-WL}{12}$

Moment at $x = \frac{L}{2}$, $M_1 = \frac{wL^2}{24} = \frac{WL}{24}$

Maximum deflection, $D = \frac{wL^4}{384\ EI} = \frac{WL^3}{384\ EI}$

13. BEAM
Constant Moment, M, applied at ends

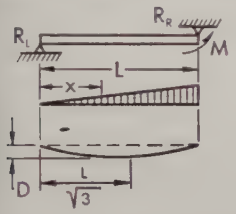


Moment at any point = M

Maximum deflection, $D = \frac{ML^2}{8\,EI}$

---

14. SIMPLE BEAM
Moment applied at one end



Reactions: $R_L = -R_R = \frac{M}{L}$

Moment at any point = $R_L x$

Maximum moment = M

Maximum deflection, $D = 0.0642\frac{ML^2}{EI}$

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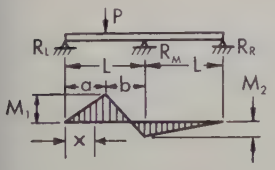
15. CONTINUOUS BEAM, TWO EQUAL SPANS
Concentrated Load, P, at any point



Reactions:

$$R_L = \frac{Pb}{4L^3}[4L^2 - a(L+a)]$$

$$R_M = \frac{Pa}{2L^3}(3L^2 - a^2)$$

$$R_R = \frac{Pa}{4L^3}(L^2 - a^2)$$

Moment at any point:

$x \leqq a,\ M = R_L x$

$a \leqq x \leqq L,\ M = R_L x - P(x-a)$

$x \geqq L,\ M = -R_R(2L-x)$

Moment at $x = L,\ M_2 = -R_R L$

Maximum moment, $M_1 = R_L a$

ELEMENTS OF SECTIONS

Elements of Sections

The data given on the following pages include the section elements commonly used in design. All values have been computed on the basis of the nominal dimensions shown. The actual dimensions of a member may vary within the plus and minus tolerances permitted for the section. Fillets and roundings have been included throughout all calculations except those for the torsion constant, J.

The moment of inertia, I, is a convenient value representing the expression, $\int y^2 dA$, which appears in the derivation of the well-known flexure formula. The term, I, appears in the formulas for deflections of beams on pages 201 through 205.

The section modulus, S, about a given axis, is the quotient obtained by dividing the moment of inertia by the distance of the extreme fiber of the section from the axis considered $\left(S = \frac{I}{c}\right)$. This term is used in calculating extreme fiber stress in beams, the stress being the bending moment divided by the section modulus.

The radius of gyration, r, about a given axis, is the square root of the quotient obtained by dividing the moment of inertia by the area of the section $\left(r = \sqrt{\frac{I}{A}}\right)$. This term is used in the determination of column strength, the length of a member divided by its radius of gyration being the slenderness ratio.

The torsion constant, J, and the torsion-bending constant, C_s, are measures of the resistance of a section to twisting. These constants are discussed in the footnotes of Table 15b, page 103. They enter into the determination of the lateral stability of beams (page 118) and twisting of columns (page 116).

The weights given in the tables of section elements are for 6061 alloy, which has a density of 0.098 lb per cu in. These weights also apply to alloys 6062 and 6063, which have the same density. Weight in pound per foot of other alloys may be found by multiplying the cross-sectional areas of the various shapes by the factors tabulated below:

Alloy	EC, 1100, 3004, 6061, 6062, 6063	2011	2014 2017 7075	2024	3003	5052 5454	5083 5086 5154 5456
Factor	1.176	1.224	1.212	1.200	1.188	1.164	1.152

Weights listed on extrusion drawings are generally based on a nominal density of 0.1 lb per cu in. and therefore differ slightly from the weights given in the following tables.

Shapes that are marketed as "standard structural shapes" are designated by the letter "S" in the column headed "Classification." The list of standard structural shapes has been developed on the basis of maximum utility and popularity. Selection of these standard shapes by the designer is strongly recommended.

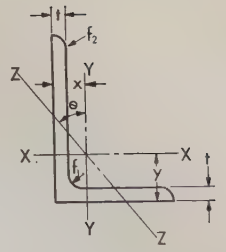
Structural shapes may be produced by either rolling or extrusion. For shapes for which there are existing extrusion dies, the die numbers are listed in the last column of the tables of section elements.

Elements of Sections

TABLE 40

angles

Elements of Sections



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
1/2x1/2	1/16	0.069	0.059	1/16	1/32	0.0013	0.0038	0.150	0.146	0.0013	0.0038	0.150	0.146	45°00′	0.0006	0.097	0.00008		78-P
5/8x5/8	3/32	0.13	0.11	1/8	3/64	0.0037	0.0084	0.183	0.187	0.0037	0.0084	0.183	0.187	45°00′	0.0015	0.117	0.00034		77-G
	1/8	0.16	0.14	1/16	1/16	0.0046	0.0109	0.182	0.199	0.0046	0.0109	0.182	0.199	45°00′	0.0020	0.120	0.00081		485
3/4x3/8	3/32	0.12	0.099	1/8	3/64	0.0054	0.0114	0.232	0.279	0.0009	0.0031	0.094	0.098	13°44′	0.0006	0.077	0.00031		734-A
3/4x3/4	1/16	0.11	0.090	1/8	3/32	0.0045	0.0081	0.222	0.200	0.0045	0.0081	0.222	0.200	45°00′	0.0019	0.144	0.00012		78-K
	3/32	0.16	0.13	1/8	3/32	0.0063	0.0118	0.219	0.214	0.0063	0.0118	0.219	0.214	45°00′	0.0026	0.141	0.00041		78-C
	1/8	0.20	0.17	1/8	3/32	0.0082	0.0157	0.219	0.227	0.0082	0.0157	0.219	0.227	45°00′	0.0034	0.141	0.00098	S	77-A
	3/16	0.29	0.25	1/8	3/32	0.0112	0.0224	0.214	0.251	0.0112	0.0224	0.214	0.251	45°00′	0.0049	0.141	0.00330	S	77-Q
1x5/8	1/8	0.22	0.19	1/16	1/16	0.0181	0.0279	0.312	0.351	0.0054	0.0117	0.170	0.165	20°34′	0.0033	0.132	0.00106		734-5
	1/4	0.41	0.34	1/8	1/16	0.0306	0.0507	0.298	0.396	0.0089	0.0215	0.161	0.210	9°08′	0.0084	0.156	0.00846		734-4
1x3/4	1/8	0.24	0.20	1/16	1/16	0.0194	0.0288	0.309	0.329	0.0092	0.0169	0.214	0.205	28°23′	0.0051	0.158	0.00114		734-JJ
1x1	1/16	0.14	0.12	1/16	1/32	0.0118	0.0162	0.311	0.271	0.0118	0.0162	0.311	0.271	45°00′	0.0048	0.199	0.00016		78-J
	3/32	0.21	0.18	1/8	3/32	0.0161	0.0223	0.301	0.276	0.0161	0.0223	0.301	0.276	45°00′	0.0066	0.193	0.00055	S	78-F
	1/8	0.28	0.23	1/8	3/32	0.0208	0.0293	0.298	0.290	0.0208	0.0293	0.298	0.290	45°00′	0.0085	0.191	0.00130	S	77-B
	3/16	0.40	0.34	1/8	3/32	0.0291	0.0424	0.293	0.314	0.0291	0.0424	0.293	0.314	45°00′	0.0124	0.191	0.00439	S	78-M
	1/4	0.51	0.44	1/8	3/32	0.0361	0.0544	0.287	0.336	0.0361	0.0544	0.287	0.336	45°00′	0.0162	0.193	0.01042	S	78-Z

①Classification "S" indicates standard structural shapes.

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	Θ	I	r			
1⅛x1⅛	⅛	0.31	0.27	3/16	⅛	0.030	0.037	0.33	0.32	0.030	0.037	0.33	0.32	45°00′	0.012	0.21	0.0015		78-U
1¼x¾	3/32	0.21	0.18	3/32	3/64	0.029	0.035	0.40	0.42	0.008	0.014	0.21	0.17	19°47′	0.005	0.16	0.0005	S	734-FF
1¼x1	⅛	0.31	0.27	⅛	1/16	0.040	0.047	0.39	0.39	0.023	0.031	0.29	0.27	31°51′	0.012	0.21	0.0015	S	734-HH
1¼x1¼	3/32	0.27	0.23	3/32	3/64	0.033	0.036	0.38	0.34	0.033	0.036	0.38	0.34	45°00′	0.014	0.24	0.0007		78-Y
	⅛	0.35	0.30	3/16	⅛	0.042	0.046	0.37	0.35	0.042	0.046	0.37	0.35	45°00′	0.017	0.24	0.0016	S	77-F
	3/16	0.51	0.43	3/16	⅛	0.059	0.068	0.37	0.37	0.059	0.068	0.37	0.37	45°00′	0.025	0.24	0.0055	S	78-A
	¼	0.66	0.56	3/16	⅛	0.074	0.087	0.36	0.40	0.074	0.087	0.36	0.40	45°00′	0.032	0.24	0.013	S	77-C
1½x¾	⅛	0.31	0.27	⅛	1/16	0.061	0.064	0.48	0.54	0.010	0.018	0.20	0.17	14°25′	0.007	0.16	0.0015	S	734-EE
	3/16	0.46	0.39	⅛	3/32	0.085	0.091	0.47	0.57	0.014	0.025	0.19	0.19	13°45′	0.009	0.16	0.0049	S	734-11
1½x⅞	3/16	0.48	0.41	⅛	3/32	0.090	0.093	0.47	0.54	0.022	0.034	0.23	0.23	18°08′	0.014	0.18	0.0052		734-7
1½x1	5/32	0.43	0.37	5/32	5/64	0.080	0.081	0.47	0.50	0.027	0.036	0.27	0.26	23°02′	0.015	0.20	0.0032	S	734-GG
	¼	0.66	0.56	3/16	⅛	0.117	0.122	0.46	0.53	0.040	0.057	0.27	0.29	22°23′	0.025	0.21	0.0130	S	734-WW
1½x1¼	⅛	0.38	0.33	3/16	⅛	0.070	0.066	0.46	0.44	0.044	0.047	0.37	0.32	33°59′	0.022	0.26	0.0018	S	734-CC
	3/16	0.57	0.48	3/16	⅛	0.100	0.097	0.46	0.47	0.063	0.069	0.36	0.35	33°53′	0.032	0.26	0.0060	S	734-LL
	¼	0.74	0.63	3/16	⅛	0.127	0.126	0.45	0.49	0.079	0.090	0.36	0.37	33°36′	0.041	0.26	0.0143	S	734-SS
1½x1½	3/32	0.32	0.27	3/16	⅛	0.057	0.052	0.46	0.39	0.057	0.052	0.46	0.39	45°00′	0.024	0.29	0.0008		78-JJ
	⅛	0.43	0.36	3/16	⅛	0.074	0.068	0.45	0.41	0.074	0.068	0.45	0.41	45°00′	0.031	0.29	0.0020	S	77-R
	3/16	0.62	0.53	3/16	⅛	0.107	0.100	0.45	0.44	0.107	0.100	0.45	0.44	45°00′	0.044	0.29	0.0066	S	77-L
	¼	0.81	0.69	3/16	⅛	0.135	0.130	0.44	0.46	0.135	0.130	0.44	0.46	45°00′	0.057	0.29	0.016	S	77-D
	5/16	0.99	0.84	3/16	⅛	0.161	0.158	0.44	0.48	0.161	0.158	0.44	0.48	45°00′	0.070	0.29	0.031		78-N
	⅜	1.16	0.99	3/16	⅛	0.184	0.185	0.43	0.51	0.184	0.185	0.43	0.51	45°00′	0.083	0.29	0.053		78-DD
1⅝x1¼	⅛	0.40	0.34	⅛	⅛	0.087	0.077	0.51	0.50	0.045	0.048	0.36	0.31	29°55′	0.024	0.26	0.0019		734-2
1¾x1⅛	3/16	0.60	0.51	3/16	3/32	0.152	0.132	0.55	0.59	0.049	0.058	0.31	0.29	21°47′	0.029	0.24	0.0063		734-E

①Classification "S" indicates standard structural shapes.

Continued on next page

TABLE 40 [illegible] **Elements of Sections**

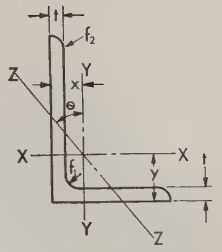
Continued

All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}



Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
1¾x1¼	⅛	0.42	0.36	3/16	⅛	0.108	0.090	0.55	0.54	0.046	0.048	0.36	0.30	26°22′	0.026	0.27	0.0020	S	734-V
	3/16	0.62	0.53	3/16	⅛	0.156	0.132	0.54	0.57	0.066	0.071	0.35	0.32	26°08′	0.037	0.26	0.0066	S	734-O
	¼	0.81	0.69	3/16	⅛	0.199	0.172	0.54	0.60	0.083	0.092	0.35	0.35	25°47′	0.048	0.26	0.016	S	734-XX
1¾x1¾	3/32	0.38	0.32	3/32	3/64	0.096	0.075	0.55	0.47	0.096	0.075	0.55	0.47	45°00′	0.039	0.35	0.0010		78-L
	⅛	0.51	0.42	3/16	⅛	0.121	0.094	0.53	0.47	0.121	0.094	0.53	0.47	45°00′	0.050	0.34	0.0023	S	77-E
	3/16	0.74	0.63	3/16	⅛	0.174	0.139	0.53	0.50	0.174	0.139	0.53	0.50	45°00′	0.072	0.34	0.0077	S	77-U
	¼	0.96	0.81	3/16	⅛	0.223	0.181	0.52	0.52	0.223	0.181	0.52	0.52	45°00′	0.093	0.34	0.018	S	77-W
	5/16	1.17	1.00	3/16	⅛	0.266	0.221	0.52	0.55	0.266	0.221	0.52	0.55	45°00′	0.113	0.34	0.036	S	78-KK
2x1¼	⅛	0.46	0.39	3/16	⅛	0.158	0.117	0.63	0.65	0.047	0.049	0.35	0.28	21°05′	0.028	0.27	0.0021		734-P
	3/16	0.68	0.58	3/16	⅛	0.228	0.172	0.63	0.68	0.068	0.072	0.34	0.31	20°52′	0.041	0.27	0.0071		734-N
	¼	0.88	0.75	3/16	⅛	0.291	0.224	0.62	0.70	0.086	0.093	0.34	0.33	20°31′	0.053	0.26	0.017		734-12
2x1⅜	¼	0.93	0.79	¼	⅛	0.302	0.228	0.62	0.68	0.114	0.113	0.38	0.37	24°14′	0.067	0.29	0.018		734-KK
2x1½	⅛	0.50	0.42	3/16	⅛	0.17	0.12	0.63	0.60	0.08	0.07	0.44	0.36	28°44′	0.04	0.32	0.0023	S	734-TT
	3/16	0.73	0.62	3/16	⅛	0.24	0.18	0.62	0.63	0.12	0.10	0.43	0.38	28°36′	0.06	0.32	0.0077	S	734-M
	¼	0.96	0.81	3/16	⅛	0.31	0.23	0.62	0.66	0.15	0.14	0.43	0.41	28°20′	0.08	0.32	0.018	S	734-W
	5/16	1.17	1.00	3/16	⅛	0.37	0.28	0.61	0.68	0.18	0.16	0.42	0.43	28°00′	0.10	0.32	0.036		734-20
	⅜	1.38	1.17	3/16	⅛	0.43	0.33	0.60	0.70	0.20	0.19	0.41	0.45	27°37′	0.12	0.32	0.062	S	734-VV

①Classification "S" indicates standard structural shapes.

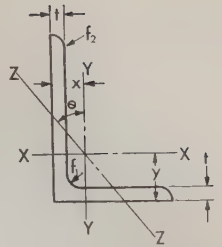
Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
2x1¾	¼	1.04	0.88	¼	⅛	0.33	0.24	0.61	0.62	0.23	0.18	0.51	0.49	34°44′	0.11	0.36	0.020		734-13
2x2	⅛	0.57	0.49	¼	⅛	0.18	0.13	0.61	0.53	0.18	0.13	0.61	0.53	45°00′	0.08	0.40	0.0026	S	77-V
	3/16	0.85	0.72	¼	⅛	0.27	0.19	0.61	0.56	0.27	0.19	0.61	0.56	45°00′	0.11	0.39	0.0088	S	77-S
	¼	1.11	0.94	¼	⅛	0.34	0.24	0.60	0.58	0.34	0.24	0.60	0.58	45°00′	0.14	0.39	0.021	S	77-P
	5/16	1.36	1.16	¼	⅛	0.41	0.30	0.60	0.61	0.41	0.30	0.60	0.61	45°00′	0.17	0.39	0.041	S	77-M
	⅜	1.59	1.37	¼	⅛	0.47	0.35	0.59	0.63	0.47	0.35	0.59	0.63	45°00′	0.20	0.39	0.070	S	77-X
2¼x1½	¼	1.04	0.88	¼	⅛	0.43	0.29	0.70	0.76	0.15	0.14	0.42	0.39	23°09′	0.09	0.32	0.020		734-MM
2½x1¼	⅛	0.54	0.46	3/16	3/32	0.30	0.18	0.81	0.87	0.05	0.05	0.34	0.25	14°45′	0.03	0.27	0.0024		734-6
	3/16	0.80	0.68	¼	3/32	0.43	0.27	0.80	0.89	0.07	0.08	0.33	0.28	14°29′	0.05	0.27	0.0082		734-H
	¼	1.04	0.88	¼	3/32	0.55	0.35	0.79	0.92	0.09	0.10	0.32	0.30	14°10′	0.06	0.26	0.020		
2½x1½	⅛	0.57	0.49	3/16	3/32	0.32	0.19	0.81	0.81	0.09	0.07	0.42	0.32	19°57′	0.05	0.33	0.0026		734-36
	3/16	0.85	0.72	¼	⅛	0.46	0.27	0.79	0.84	0.12	0.11	0.41	0.35	19°38′	0.08	0.32	0.0088	S	734-T
	¼	1.11	0.94	¼	⅛	0.59	0.36	0.79	0.86	0.16	0.14	0.41	0.37	19°25′	0.10	0.32	0.021	S	734-RR
	5/16	1.36	1.16	3/16	⅛	0.71	0.44	0.78	0.89	0.19	0.17	0.40	0.39	19°06′	0.12	0.32	0.041	S	734-8
	⅜	1.61	1.37	¼	⅛	0.82	0.51	0.77	0.91	0.22	0.20	0.40	0.42	18°42′	0.14	0.32	0.070		
2½x2	⅛	0.65	0.55	¼	⅛	0.34	0.19	0.79	0.72	0.20	0.13	0.60	0.48	31°57′	0.10	0.43	0.0029	S	734-S
	3/16	0.96	0.82	¼	⅛	0.50	0.29	0.78	0.75	0.29	0.19	0.59	0.51	31°58′	0.15	0.42	0.010	S	734-U
	¼	1.26	1.07	¼	⅛	0.65	0.38	0.78	0.78	0.37	0.25	0.58	0.53	31°51′	0.19	0.42	0.023	S	734-3
	5/16	1.55	1.32	¼	⅛	0.78	0.46	0.77	0.80	0.44	0.30	0.58	0.55	31°41′	0.23	0.42	0.046	S	734-B
	⅜	1.83	1.55	¼	⅛	0.91	0.54	0.76	0.83	0.51	0.36	0.57	0.58	31°28′	0.27	0.42	0.079	S	
2½x2½	⅛	0.72	0.62	¼	⅛	0.37	0.20	0.77	0.65	0.37	0.20	0.77	0.65	45°00′	0.15	0.50	0.0033	S	78-BB
	3/16	1.07	0.91	¼	⅛	0.54	0.30	0.77	0.68	0.54	0.30	0.77	0.68	45°00′	0.22	0.49	0.011	S	77-T
	¼	1.40	1.19	¼	⅛	0.69	0.39	0.76	0.71	0.69	0.39	0.76	0.71	45°00′	0.29	0.49	0.026	S	78-H
	5/16	1.73	1.47	¼	⅛	0.84	0.48	0.76	0.73	0.84	0.48	0.76	0.73	45°00′	0.35	0.49	0.051	S	78-FF
	⅜	2.05	1.74	¼	⅛	0.98	0.56	0.75	0.76	0.98	0.56	0.75	0.76	45°00′	0.41	0.48	0.088	S	78-B
	7/16	2.36	2.00	¼	⅛	1.10	0.64	0.74	0.78	1.10	0.64	0.74	0.78	45°00′	0.47	0.48	0.140		77-N
	½	2.65	2.26	¼	⅛	1.22	0.72	0.73	0.80	1.22	0.72	0.73	0.80	45°00′	0.53	0.48	0.208		

①Classification "S" indicates standard structural shapes.

Continued on next page

TABLE 40 angles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
3x1½	¼	1.27	1.08	5/16	⅛	0.98	0.51	0.95	1.08	0.16	0.14	0.39	0.34	14°22′	0.11	0.32	0.023		734-L
3x2	3/16	1.07	0.91	5/16	3/16	0.82	0.40	0.95	0.94	0.29	0.19	0.56	0.46	23°25′	0.17	0.43	0.011	S	734-1
	¼	1.40	1.19	5/16	3/16	1.06	0.52	0.94	0.97	0.38	0.25	0.56	0.48	23°22′	0.22	0.43	0.026	S	734-G
	5/16	1.73	1.47	5/16	3/16	1.29	0.65	0.94	1.00	0.45	0.30	0.56	0.51	23°13′	0.27	0.43	0.051	S	734-10
	⅜	2.05	1.74	5/16	3/16	1.51	0.76	0.93	1.03	0.53	0.36	0.55	0.53	23°00′	0.31	0.42	0.088	S	734-PP
	7/16	2.35	2.00	5/16	3/16	1.71	0.88	0.92	1.05	0.59	0.41	0.55	0.56	22°44′	0.36	0.42	0.140	S	734-QQ
	½	2.65	2.26	5/16	3/16	1.90	0.99	0.92	1.07	0.66	0.46	0.54	0.58	22°25′	0.40	0.42	0.208		
3x2½	¼	1.54	1.31	5/16	¼	1.12	0.53	0.92	0.89	0.70	0.38	0.73	0.64	34°03′	0.35	0.52	0.029	S	734-J
	5/16	1.90	1.62	5/16	¼	1.37	0.66	0.92	0.92	0.86	0.47	0.73	0.67	34°00′	0.43	0.51	0.056	S	734-ZZ
	⅜	2.25	1.92	5/16	¼	1.60	0.78	0.91	0.94	1.00	0.55	0.72	0.69	33°54′	0.51	0.51	0.097	S	734-C
	7/16	2.60	2.21	5/16	¼	1.82	0.90	0.91	0.97	1.14	0.64	0.72	0.72	33°46′	0.58	0.51	0.154		
	½	2.93	2.49	5/16	¼	2.03	1.01	0.90	0.99	1.26	0.72	0.71	0.74	33°37′	0.65	0.51	0.229		734-55
3x3	3/16	1.28	1.09	5/16	¼	0.91	0.41	0.91	0.79	0.91	0.41	0.91	0.79	45°00′	0.37	0.59	0.013	S	78-AA
	¼	1.68	1.43	5/16	¼	1.18	0.54	0.91	0.82	1.18	0.54	0.91	0.82	45°00′	0.49	0.58	0.031	S	77-H
	5/16	2.08	1.77	5/16	¼	1.45	0.67	0.91	0.85	1.45	0.67	0.91	0.85	45°00′	0.60	0.58	0.061	S	78-E
	⅜	2.47	2.10	5/16	¼	1.70	0.80	0.90	0.87	1.70	0.80	0.90	0.87	45°00′	0.70	0.58	0.105	S	77-K
	7/16②	2.86	2.43	5/16	¼	1.94	0.92	0.89	0.90	1.94	0.92	0.89	0.90	45°00′	0.81	0.58	0.167	S	
	½③	3.23	2.74	5/16	¼	2.16	1.04	0.89	0.92	2.16	1.04	0.89	0.92	45°00′	0.91	0.58	0.250	S	78-T

①Classification "S" indicates standard structural shapes.

②③See footnotes, page 219.

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	Θ	I	r			
3½x2½	¼	1.68	1.43	5/16	¼	1.73	0.72	1.10	1.09	0.73	0.38	0.71	0.60	26°23′	0.41	0.53	0.031	S	734-D
	5/16	2.08	1.77	5/16	¼	2.12	0.89	1.09	1.12	0.89	0.48	0.71	0.62	26°18′	0.50	0.53	0.061	S	734-UU
	⅜	2.47	2.10	5/16	¼	2.49	1.06	1.09	1.14	1.05	0.57	0.71	0.65	26°10′	0.59	0.53	0.105	S	734-24
	7/16	2.86	2.43	5/16	¼	2.84	1.22	1.08	1.17	1.19	0.65	0.70	0.67	26°00′	0.67	0.53	0.167		
	½	3.23	2.74	5/16	¼	3.17	1.37	1.08	1.19	1.32	0.73	0.69	0.70	25°48′	0.76	0.53	0.250	S	734-23
3½x3	¼	1.84	1.57	⅜	¼	1.84	0.74	1.08	1.01	1.28	0.57	0.90	0.76	36°13′	0.63	0.63	0.034	S	734-BB
	5/16	2.28	1.94	⅜	¼	2.26	0.92	1.08	1.04	1.52	0.69	0.89	0.79	35°40′	0.74	0.62	0.066	S	734-22
	⅜	2.70	2.30	⅜	¼	2.65	1.09	1.07	1.06	1.79	0.82	0.88	0.82	35°37′	0.87	0.62	0.114	S	734-27
	7/16	3.12	2.66	⅜	¼	3.03	1.26	1.07	1.09	2.04	0.94	0.88	0.84	35°32′	1.00	0.61	0.181		734-39
	½	3.53	3.00	⅜	¼	3.38	1.42	1.06	1.11	2.27	1.06	0.87	0.86	35°26′	1.13	0.61	0.271	S	734-NN
3½x3½	¼	1.99	1.69	⅜	¼	1.93	0.76	1.07	0.94	1.93	0.76	1.07	0.94	45°00′	0.80	0.69	0.036	S	78-G
	5/16	2.46	2.09	⅜	¼	2.37	0.94	1.06	0.97	2.37	0.94	1.06	0.97	45°00′	0.98	0.68	0.071	S	78-CC
	⅜	2.93	2.49	⅜	¼	2.79	1.11	1.06	1.00	2.79	1.11	1.06	1.00	45°00′	1.15	0.68	0.123	S	78-GG
	7/16	3.38	2.87	⅜	¼	3.18	1.28	1.05	1.02	3.18	1.28	1.05	1.02	45°00′	1.32	0.68	0.195		
	½	3.83	3.25	⅜	¼	3.56	1.45	1.05	1.05	3.56	1.45	1.05	1.05	45°00′	1.49	0.68	0.292	S	77-Z
4x3	¼	1.99	1.69	⅜	¼	2.68	0.96	1.26	1.21	1.29	0.56	0.87	0.72	28°42′	0.70	0.64	0.036	S	734-31
	5/16	2.46	2.09	⅜	¼	3.29	1.19	1.25	1.24	1.58	0.70	0.87	0.74	28°40′	0.85	0.64	0.071	S	734-Z
	⅜	2.93	2.49	⅜	¼	3.88	1.42	1.25	1.26	1.86	0.83	0.86	0.77	28°35′	1.01	0.64	0.123	S	734-Y
	7/16	3.38	2.87	⅜	¼	4.43	1.63	1.24	1.29	2.12	0.96	0.86	0.79	28°28′	1.15	0.63	0.195	S	734-X
	½	3.83	3.25	⅜	¼	4.96	1.85	1.24	1.31	2.36	1.08	0.85	0.82	28°20′	1.30	0.63	0.292	S	734-42
	⅝	4.69	3.99	⅜	¼	5.95	2.25	1.22	1.36	2.82	1.32	0.84	0.86	28°00′	1.58	0.63	0.570	S	734-54
4x3½	5/16	2.63	2.23	⅜	5/16	3.40	1.19	1.23	1.15	2.42	0.93	1.04	0.91	36°54′	1.15	0.72	0.076		734-41
	⅜	3.13	2.66	⅜	5/16	4.02	1.43	1.23	1.18	2.85	1.11	1.04	0.94	36°53′	1.36	0.72	0.132	S	734-AA
	7/16	3.62	3.08	⅜	5/16	4.61	1.65	1.22	1.21	3.27	1.29	1.03	0.96	36°50′	1.57	0.71	0.209		
	½	4.10	3.49	⅜	5/16	5.17	1.87	1.22	1.23	3.67	1.46	1.03	0.99	36°46′	1.77	0.71	0.313	S	734-30
4x4	¼	2.28	1.94	⅜	¼	2.94	1.00	1.23	1.07	2.94	1.00	1.23	1.07	45°00′	1.21	0.79	0.042	S	78-MM
	5/16	2.83	2.41	⅜	¼	3.61	1.24	1.23	1.10	3.61	1.24	1.23	1.10	45°00′	1.48	0.78	0.081	S	77-Y
	⅜	3.38	2.86	⅜	¼	4.26	1.48	1.22	1.12	4.26	1.48	1.22	1.12	45°00′	1.75	0.78	0.141	S	77-O
	7/16	3.90	3.31	⅜	¼	4.87	1.71	1.21	1.15	4.87	1.71	1.21	1.15	45°00′	2.01	0.78	0.223	S	78-YY
	½	4.41	3.75	⅜	¼	5.46	1.93	1.21	1.17	5.46	1.93	1.21	1.17	45°00′	2.26	0.78	0.333	S	78-LL

①Classification "S" indicates standard structural shapes.

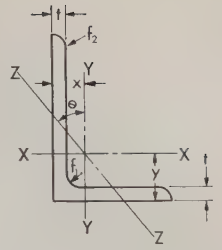
Continued on next page

TABLE 40

angles

Elements of Sections

Concluded



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
4x4	9/16	4.92	4.19	3/8	1/4	6.02	2.15	1.20	1.20	6.02	2.15	1.20	1.20	45°00′	2.51	0.77	0.475	S	
	5/8	5.42	4.61	3/8	1/4	6.56	2.36	1.19	1.22	6.56	2.36	1.19	1.22	45°00′	2.76	0.77	0.651	S	
	11/16④	5.92	5.03	3/8	1/4	7.08	2.57	1.19	1.24	7.08	2.57	1.19	1.24	45°00′	3.00	0.77	0.867	S	78-VV
	3/4⑥	6.40	5.44	3/8	1/4	7.57	2.77	1.18	1.26	7.57	2.77	1.18	1.26	45°00′	3.25	0.77	1.125	S	78-PP
5x2½	1/2	4.12	3.50	3/8	1/4	8.74	2.77	1.58	1.84	1.46	0.77	0.64	0.60	14°12′	0.96	0.52	0.313		734-DD
5x3	3/8	3.35	2.85	3/8	5/16	7.15	2.15	1.59	1.68	1.93	0.84	0.82	0.69	19°40′	1.17	0.64	0.141	S	734-Q
	1/2	4.40	3.74	3/8	5/16	9.24	2.83	1.57	1.73	2.48	1.10	0.81	0.74	19°26′	1.52	0.64	0 333	S	734-38
5x3½	5/16	3.01	2.56	7/16	5/16	6.39	1.85	1.58	1.55	2.58	0.96	1.00	0.81	25°33′	1.45	0.75	0.09	S	734-45
	3/8	3.58	3.05	7/16	5/16	7.56	2.21	1.58	1.58	3.04	1.15	1.00	0.84	25°32′	1.71	0.75	0.15	S	734-47
	7/16	4.15	3.53	7/16	5/16	8.69	2.56	1.57	1.61	3.49	1.33	0.99	0.87	25°27′	1.97	0.75	0.24	S	
	1/2	4.70	4.00	7/16	5/16	9.77	2.90	1.56	1.63	3.91	1.50	0.99	0.89	25°22′	2.22	0.74	0.35	S	734-14
	5/8	5.79	4.92	7/16	5/16	11.82	3.56	1.55	1.68	4.70	1.84	0.98	0.94	25°07′	2.70	0.74	0.69	S	
	3/4	6.83	5.81	1/2	3/8	13.62	4.16	1.53	1.73	5.37	2.14	0.96	0.98	24°45′	3.14	0.74	1.20		734-33
5x5	3/8	4.28	3.60	1/2	3/8	8.37	2.30	1.52	1.36	8.37	2.30	1.52	1.36	45°00′	3.44	0.98	0.18	S	77-J
	7/16	4.91	4.18	1/2	3/8	9.65	2.67	1.52	1.38	9.65	2.67	1.52	1.38	45°00′	3.96	0.97	0.28	S	78-X
	1/2	5.58	4.74	1/2	3/8	10.89	3.03	1.52	1.41	10.89	3.03	1.52	1.41	45°00′	4.47	0.97	0.42	S	78-RR
	5/8	6.88	5.85	1/2	3/8	13.22	3.73	1.50	1.46	13.22	3.73	1.50	1.46	45°00′	5.47	0.97	0.81	S	78-QQ
	3/4	8.15	6.93	1/2	3/8	15.39	4.41	1.49	1.51	15.39	4.41	1.49	1.51	45°00′	6.44	0.96	1.41		

①Classification "S" indicates standard structural shapes.

④⑥See footnotes, page 219.

Size		Weight	Area	f_1	f_2	Axis X-X				Axis Y-Y				Axis Z-Z			J	Classification① and Extrusion Section Numbers	
Legs	t					I	S	r	y	I	S	r	x	θ	I	r			
6x3½	5/16	3.39	2.88	½	5/16	10.64	2.64	1.92	1.97	2.70	0.98	0.97	0.74	18°52′	1.65	0.76	0.10	S	734-35
	3/8	4.04	3.43	½	5/16	12.60	3.15	1.92	2.00	3.19	1.17	0.96	0.77	18°51′	1.95	0.75	0.17	S	734-R
	½	5.31	4.51	½	5/16	16.34	4.14	1.90	2.06	4.11	1.53	0.95	0.82	18°42′	2.52	0.75	0.40	S	734-9
	5/8	6.54	5.56	½	5/16	19.83	5.09	1.89	2.11	4.94	1.88	0.94	0.87	18°28′	3.07	0.74	0.77		734-26
6x4	3/8	4.24	3.60	½	3/8	13.02	3.17	1.90	1.90	4.63	1.50	1.13	0.91	23°33′	2.67	0.86	0.18	S	734-43
	7/16	4.91	4.18	½	3/8	15.02	3.69	1.90	1.93	5.34	1.74	1.13	0.94	23°31′	3.07	0.86	0.28	S	734-53
	½	5.58	4.74	½	3/8	16.95	4.19	1.89	1.96	6.01	1.98	1.13	0.97	23°27′	3.47	0.86	0.42	S	734-44
	9/16	6.24	5.30	½	3/8	18.82	4.69	1.88	1.98	6.65	2.21	1.12	0.99	23°22′	3.86	0.85	0.59	S	
	5/8	6.88	5.85	½	3/8	20.63	5.17	1.88	2.01	7.27	2.44	1.11	1.02	23°16′	4.24	0.85	0.81	S	734-52
	¾④	8.15	6.93	½	3/8	24.08	6.11	1.86	2.06	8.43	2.87	1.10	1.07	23°02′	4.98	0.85	1.41	S	
6x6	3/8	5.12	4.35	½	3/8	14.85	3.38	1.85	1.60	14.85	3.38	1.85	1.60	45°00′	6.07	1.18	0.21	S	78-Q
	7/16	5.94	5.05	½	3/8	17.15	3.93	1.84	1.63	17.15	3.93	1.84	1.63	45°00′	7.01	1.18	0.34	S	78-V
	½	6.75	5.74	½	3/8	19.38	4.46	1.84	1.66	19.38	4.46	1.84	1.66	45°00′	7.92	1.17	0.50	S	78-S
	9/16	7.56	6.43	½	3/8	21.54	4.99	1.83	1.68	21.54	4.99	1.83	1.68	45°00′	8.82	1.17	0.71		
	5/8	8.35	7.10	½	3/8	23.64	5.51	1.82	1.71	23.64	5.51	1.82	1.71	45°00′	9.70	1.17	0.98	S	78-HH
	11/16	9.14	7.77	½	3/8	25.67	6.02	1.82	1.73	25.67	6.02	1.82	1.73	45°00′	10.57	1.17	1.30		78-W
	¾	9.91	8.43	½	3/8	27.64	6.52	1.81	1.76	27.64	6.52	1.81	1.76	45°00′	11.43	1.16	1.69		78-XX
8x6	5/8	9.84	8.37	½	5/16	53.57	9.74	2.53	2.50	25.94	5.77	1.76	1.50	28°52′	13.89	1.29	1.14	S	734-34
	11/16	10.76	9.15	½	3/8	57.99	10.58	2.52	2.52	27.98	6.25	1.75	1.53	28°47′	15.02	1.28	1.52	S	734-37
	¾	11.68	9.93	½	3/8	62.60	11.47	2.51	2.54	30.15	6.77	1.74	1.55	28°43′	16.24	1.28	1.97	S	734-32
8x8	½	9.14	7.77	5/8	3/8	47.74	8.16	2.48	2.15	47.74	8.16	2.48	2.15	45°00′	19.51	1.58	0.67	S	78-SS
	¾	13.48	11.46	5/8	3/8	68.86	11.99	2.45	2.26	68.86	11.99	2.45	2.26	45°00′	28.20	1.57	2.25	S	78-TT
	1	17.67	15.02	5/8	3/8	88.11	15.60	2.42	2.35	88.11	15.60	2.42	2.35	45°00′	36.46	1.56	5.33	S	78-UU

①Classification "S" indicates standard structural shapes.
②Nominal rolled size in this thickness is 3 5/32″x3 5/32″. Section elements given are for 3″x3″ size.
③Nominal rolled size in this thickness is 3 5/32″x3 5/32″. Section elements given are for 3″x3″ size.
④Nominal rolled size in this thickness is 4 3/16″x4 3/16″. Section elements given are for 4″x4″ size.
⑤Nominal rolled size in this thickness is 4 1/4″x4 1/4″. Section elements given are for 4″x4″ size.
⑥Nominal rolled size in this thickness is 6 3/16″x4 3/16″. Section elements given are for 6″x4″ size.

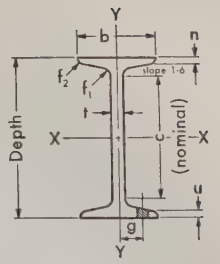
TABLE 41

I-beams

Elements of Sections

(AMERICAN STANDARD)

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.[4]
S = Section Modulus in in.[3]
r = Radius of Gyration in inches.
J = Torsion Constant in in.[4]
C_s = Torsion-bending Constant in in.[6]
Rivet given is largest recommended in flange in inches.
g = Usual gage in inches.
u = Nominal grip in inches.



Size			Area	b	n	f_1	f_2	c	Axis X-X			Axis Y-Y			J	C_s	Rivet Data			Classification① & Extrusion Section Numbers	
Depth	Weight	t							I	S	r	I	S	r			Dia.	g	u		
3	1.96	0.170	1.67	2.330	0.17	0.27	0.10	1¾	2.52	1.68	1.23	0.46	0.39	0.52	0.045	0.85	⅜	¾	5/16	S	851-A
	2.25	0.251	1.91	2.411	0.17	0.27	0.10	1¾	2.71	1.80	1.19	0.51	0.42	0.52	0.061	0.94	⅜	¾	5/16		851-J
	2.59	0.349	2.21	2.509	0.17	0.27	0.10	1¾	2.93	1.95	1.15	0.59	0.47	0.52	0.093	1.08	⅜	¾	5/16	S	851-D
4	2.64	0.190	2.25	2.660	0.19	0.29	0.11	2¾	6.06	3.03	1.64	0.76	0.57	0.58	0.074	2.58	½	¾	5/16	S	851-B
	3.28	0.326	2.79	2.796	0.19	0.29	0.11	2¾	6.79	3.39	1.56	0.90	0.65	0.57	0.12	3.04	½	¾	5/16	S	851-F
5	3.43	0.210	2.92	3.000	0.21	0.31	0.13	3½	12.26	4.90	2.05	1.21	0.81	0.64	0.12	6.54	½	⅞	⅜	S	851-C
	4.23	0.347	3.60	3.137	0.21	0.31	0.13	3½	13.69	5.48	1.95	1.41	0.90	0.63	0.19	7.60	½	⅞	⅜		851-E
	5.10	0.494	4.34	3.284	0.21	0.31	0.13	3½	15.22	6.09	1.87	1.66	1.01	0.62	0.33	8.92	½	⅞	⅜	S	851-O
6	4.30	0.230	3.66	3.330	0.23	0.33	0.14	4½	22.08	7.36	2.46	1.82	1.09	0.71	0.17	14.34	5/8	1	⅜	S	851-K
	5.10	0.343	4.34	3.443	0.23	0.33	0.14	4½	24.11	8.04	2.36	2.04	1.19	0.69	0.24	16.04	5/8	1	⅜	S	851-L
	5.96	0.465	5.07	3.565	0.23	0.33	0.14	4½	26.31	8.77	2.28	2.31	1.30	0.68	0.38	18.12	5/8	1	⅜		851-S
7	5.27	0.250	4.48	3.660	0.25	0.35	0.15	5¼	36.69	10.48	2.86	2.63	1.44	0.77	0.25	28.45	5/8	1⅛	⅜		
	6.05	0.345	5.15	3.755	0.25	0.35	0.15	5¼	39.40	11.26	2.77	2.88	1.53	0.75	0.32	31.11	5/8	1⅛	⅜	S	851-H
	6.92	0.450	5.88	3.860	0.25	0.35	0.15	5¼	42.40	12.12	2.69	3.17	1.64	0.73	0.46	34.19	5/8	1⅛	⅜		
8	6.35	0.270	5.40	4.000	0.27	0.37	0.16	6¼	57.55	14.39	3.27	3.73	1.86	0.83	0.34	53.04	¾	1⅛	7/16	S	851-G
	7.96	0.441	6.77	4.171	0.27	0.37	0.16	6¼	64.85	16.21	3.10	4.31	2.07	0.80	0.56	61.16	¾	1⅛	7/16		
	8.81	0.532	7.49	4.262	0.27	0.37	0.16	6¼	68.73	17.18	3.03	4.66	2.19	0.79	0.75	66.04	¾	1⅛	½	S	851-M

①Classification "S" indicates standard structural shapes.

Size			Area	b	n	f_1	f_2	c	Axis X-X			Axis Y-Y			J	C_S	Rivet Data			Classification① & Extrusion Section Numbers	
Depth	Weight	t							I	S	r	I	S	r			Dia.	g	u		
9	7.51	0.290	6.38	4.330	0.29	0.39	0.17	7	85.90	19.09	3.67	5.09	2.35	0.89	0.46	92.09	¾	1¼	½		851-N
10	8.76	0.310	7.45	4.660	0.31	0.41	0.19	8	123.39	24.68	4.07	6.78	2.91	0.95	0.62	152.04	¾	1⅜	½	S	851-P
	10.37	0.447	8.82	4.797	0.31	0.41	0.19	8	134.81	26.96	3.91	7.50	3.13	0 92	0.86	167.94	¾	1⅜	½		851-V
	12.10	0.594	10.29	4.944	0.31	0.41	0.19	8	147.06	29.41	3.78	8.36	3.38	0.90	1.31	186.92	¾	1⅜	½		851-R
12	10.99	0.350	9.35	5.000	0.35	0.45	0.21	9¾	218.13	36.35	4.83	9.35	3.74	1.00	0.92	304.64	¾	1½	9/16	S	851-T
	12.09	0.428	10.28	5.078	0.35	0.45	0.21	9¾	229.36	38.23	4.72	9.87	3.89	0.98	1.10	321.25	¾	1½	9/16		851-X
	14.08	0.460	11.97	5.250	0.46	0.56	0.28	9¼	272.15	45.36	4.77	13.54	5.16	1.06	1.78	432.08	¾	1½	¾		851-U
	15.56	0.565	13.23	5.355	0.46	0.56	0.28	9¼	287.27	47.88	4.66	14.50	5.42	1.05	2.19	462.30	¾	1½	¾		851-Q
	17.28	0.687	14.70	5.477	0.46	0.56	0.28	9¼	304.84	50.81	4.56	15.71	5.74	1.03	2.85	500.35	¾	1¾	¾		66136

①Classification "S" indicates standard structural shapes.

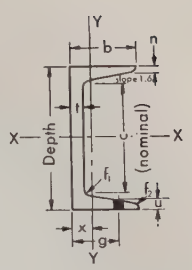
TABLE 42

channels

Elements of Sections

(AMERICAN STANDARD)

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.[4]
S = Section Modulus in in.[3]
r = Radius of Gyration in inches.
J = Torsion Constant in in.[4]
C_s = Torsion-bending Constant in in.[6]
Rivet given is largest recommended in flange in inches.
g = Usual gage in inches.
u = Nominal grip in inches.



Size			Area	b	n	f_1	f_2	c	Axis X-X			Axis Y-Y				J	C_s	Rivet data			Classification① & Extrusion Section Numbers	
Depth	Weight	t							I	S	r	I	S	r	x			Dia.	g	u		
3	1.42	0.170	1.21	1.410	0.17	0.27	0.10	1¾	1.66	1.10	1.17	0.20	0.20	0.40	0.44	0.031	0.27	½	⅞	¼	S	852-A
	1.48	0.187	1.26	1.427	0.17	0.27	0.10	1¾	1.69	1.13	1.16	0.21	0.21	0.41	0.44	0.033	0.29	½	⅞	¼		852-Z
	1.73	0.258	1.47	1.498	0.17	0.27	0.10	1¾	1.85	1.24	1.12	0.25	0.23	0.41	0.44	0.047	0.34	½	⅞	¼	S	852-S
	1.95	0.320	1.66	1.560	0.17	0.27	0.10	1¾	1.99	1.33	1.10	0.28	0.25	0.41	0.45	0.066	0.38	½	⅞	¼		852-AB
	2.07	0.356	1.76	1.596	0.17	0.27	0.10	1¾	2.07	1.38	1.08	0.31	0.27	0.42	0.46	0.080	0.42	½	⅞	¼	S	852-D
4	1.85	0.180	1.57	1.580	0.18	0.28	0.11	2¾	3.83	1.92	1.56	0.32	0.28	0.45	0.46	0.045	0.80	½	1	5/16	S	852-B
	2.16	0.247	1.84	1.647	0.18	0.28	0.11	2¾	4.19	2.10	1.51	0.37	0.31	0.45	0.45	0.062	0.93	½	1	5/16	S	852-G
	2.50	0.320	2.13	1.720	0.18	0.28	0.11	2¾	4.58	2.29	1.47	0.43	0.34	0.45	0.46	0.090	1.09	½	1	5/16	S	852-E
5	2.32	0.190	1.97	1.750	0.19	0.29	0.11	3½	7.49	3.00	1.95	0.48	0.38	0.49	0.48	0.064	1.92	½	1⅛	5/16	S	852-C
	3.11	0.325	2.64	1.885	0.19	0.29	0.11	3½	8.90	3.56	1.83	0.63	0.45	0.49	0.48	0.12	2.52	½	1⅛	5/16	S	
	3.97	0.472	3.38	2.032	0.19	0.29	0.11	3½	10.43	4.17	1.76	0.81	0.53	0.49	0.51	0.25	3.34	½	1⅛	5/16	S	852-AG
6	2.83	0.200	2.40	1.920	0.20	0.30	0.12	4½	13.12	4.37	2.34	0.69	0.49	0.54	0.51	0.088	4.06	⅝	1⅛	5/16	S	852-F
	3.00	0.225	2.55	1.945	0.20	0.30	0.12	4½	13.57	4.52	2.31	0.73	0.51	0.54	0.51	0.097	4.27	⅝	1⅛	5/16	S	852-AA
	3.63	0.314	3.09	2.034	0.20	0.30	0.12	4½	15.18	5.06	2.22	0.87	0.56	0.53	0.50	0.14	5.14	⅝	1⅛	⅜	S	852-V
	4.48	0.437	3.82	2.157	0.20	0.30	0.12	4½	17.39	5.80	2.13	1.05	0.64	0.52	0.51	0.26	6.34	⅝	1⅜	⅜	S	852-J

①Classification "S" indicates standard structural shapes.

Size			Area	b	n	f_1	f_2	c	Axis X-X			Axis Y-Y				J	C_s	Rivet data			Classification① & Extrusion Section Numbers	
Depth	Weight	t							I	S	r	I	S	r	x			Dia.	g	u		
7	3.38	0.210	2.87	2.090	0.21	0.31	0.13	5½	21.27	6.08	2.72	0.97	0.63	0.58	0.54	0.12	7.77	⅝	1¼	⅜		
	3.54	0.230	3.01	2.110	0.21	0.31	0.13	5½	21.84	6.24	2.69	1.01	0.64	0.58	0.54	0.13	8.03	⅝	1¼	7/16	S	852-L
	4.23	0.314	3.60	2.194	0.21	0.31	0.13	5½	24.24	6.93	2.60	1.17	0.70	0.57	0.52	0.18	9.58	⅝	1¼	⅜	S	852-W
	5.10	0.419	4.33	2.299	0.21	0.31	0.13	5½	27.24	7.78	2.51	1.38	0.78	0.56	0.53	0.29	11.42	⅝	1¼	7/16	S	
	5.96	0.524	5.07	2.404	0.21	0.31	0.13	5½	30.25	8.64	2.44	1.59	0.86	0.56	0.55	0.47	13.44	⅝	1½	7/16		852-Q
8	4.25	0.250	3.62	2.290	0.22	0.32	0.13	6¼	33.85	8.46	3.06	1.40	0.81	0.62	0.56	0.17	14.83	¾	1⅜	⅜	S	852-K
	4.75	0.303	4.04	2.343	0.22	0.32	0.13	6¼	36.11	9.03	2.99	1.53	0.85	0.61	0.55	0.21	16.28	¾	1⅜	⅜	S	852-Y
	5.62	0.395	4.78	2.435	0.22	0.32	0.13	6¼	40.04	10.01	2.90	1.75	0.93	0.61	0.55	0.32	19.15	¾	1½	7/16	S	852-X
	6.48	0.487	5.51	2.527	0.22	0.32	0.13	6¼	43.96	10.99	2.82	1.98	1.01	0.60	0.57	0.47	21.57	¾	1½	7/16	S	
9	4.60	0.230	3.91	2.430	0.23	0.33	0.14	7¼	47.68	10.60	3.49	1.75	0.96	0.67	0.60	0.20	23.60	¾	1⅜	7/16	S	852-R
	5.19	0.285	4.41	2.485	0.23	0.33	0.14	7¼	51.02	11.34	3.40	1.93	1.01	0.66	0.59	0.24	25.87	¾	1⅜	7/16		852-AJ
	6.91	0.448	5.88	2.648	0.23	0.33	0.14	7¼	60.92	13.54	3.22	2.42	1.17	0.64	0.58	0.47	33.70	¾	1½	½	S	852-T
	8.65	0.612	7.35	2.812	0.23	0.33	0.14	7¼	70.89	15.75	3.11	2.94	1.34	0.63	0.61	0.92	42.36	¾	1½	½		852-U
10	5.28	0.240	4.49	2.600	0.24	0.34	0.14	8¼	67.37	13.47	3.87	2.28	1.16	0.71	0.63	0.25	37.97	¾	1½	7/16	S	852-P
	6.91	0.379	5.88	2.739	0.24	0.34	0.14	8¼	78.95	15.79	3.66	2.81	1.32	0.69	0.61	0.41	47.29	¾	1½	7/16		852-AF
	8.64	0.526	7.35	2.886	0.24	0.34	0.14	8¼	91.20	18.24	3.52	3.36	1.48	0.68	0.62	0.75	58.59	¾	1¾	½	S	852-AE
	10.37	0.673	8.82	3.033	0.24	0.34	0.14	8¼	103.45	20.69	3.43	3.95	1.66	0.67	0.65	1.32	70.94	¾	1¾	½		852-AK
12	7.41	0.300	6.30	2.960	0.28	0.38	0.17	10	131.84	21.97	4.57	3.99	1.76	0.80	0.69	0.46	96.84	⅞	1¾	½	S	
	8.64	0.387	7.35	3.047	0.28	0.38	0.17	10	144.37	24.06	4.43	4.47	1.89	0.78	0.67	0.61	109.72	⅞	1¾	½	S	852-N
	10.37	0.510	8.82	3.170	0.28	0.38	0.17	10	162.08	27.01	4.29	5.14	2.06	0.76	0.67	0.95	129.02	⅞	1¾	½	S	852-AH
	12.10	0.632	10.29	3.292	0.28	0.38	0.17	10	179.65	29.94	4.18	5.82	2.24	0.75	0.69	1.48	148.64	⅞	2	⅝		852-O
15	11.71	0.400	9.96	3.400	0.40	0.50	0.24	12⅜	314.76	41.97	5.62	9.63	3.11	0.90	0.79	1.17	361.54	1	2	⅝	S	852-AC
	17.28	0.716	14.70	3.716	0.40	0.50	0.24	12⅜	403.64	53.82	5.24	12.53	4.30	0.92	0.80	2.89	511.46	1	2	⅝	S	852-AD

①Classification "S" indicates standard structural shapes.

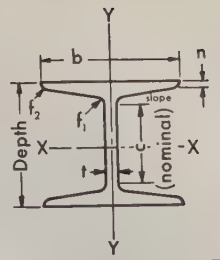
TABLE 43

wide-flange sections

(INCLUDING H-BEAMS)

Elements of Sections

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.⁴
S = Section Modulus in in.³
r = Radius of Gyration in inches.
J = Torsion Constant in in.⁴
C_s = Torsion-bending Constant in in.⁶

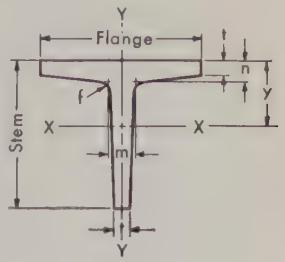


Size			Area	Actual Depth	b	Slope	n	f_1	f_2	c	Axis X-X			Axis Y-Y			J	C_s	Classification① & Extrusion Section Numbers	
Nominal Depth and Width	Weight	t									I	S	r	I	S	r				
2x2	0.78	0.094	0.664	2.00	2.000	0	0.125	0.125	0.125	1½	0.481	0.481	0.85	0.154	0.154	0.48	0.004	0.135		8606
	1.43	0.188	1.217	2.00	2.000	1:11.4	0.188	0.188	0.094	1⅛	0.782	0.782	0.80	0.275	0.275	0.47	0.025	0.214		10096
2½x2	1.80	0.250	1.529	2.50	2.000	1:7	0.188	0.250	0.125	1⅜	1.453	1.162	0.97	0.292	0.292	0.44	0.091	0.364		4465
4x4	4.76	0.313	4.05	4.00	4.000	1:11.3	0.290	0.313	0.145	2⅜	10.80	5.40	1.63	3.52	1.76	0.93	0.22	11.50	S	3002-A
5x5	6.49	0.313	5.52	5.00	5.000	1:13.6	0.330	0.313	0.165	3⅜	23.94	9.58	2.08	7.73	3.09	1.18	0.34	40.38	S	3002-B
6x4	4.16	0.230	3.54	6.00	4.000	0	0.279	0.250	0	4⅞	21.75	7.25	2.48	2.98	1.49	0.92	0.090	24.38	S	42100-D
6x6	5.40	0.240	4.59	6.00	6.000	0	0.269	0.250	0	4⅞	30.17	10.06	2.56	9.69	3.23	1.45	0.11	79.57	S	42100-H
	7.85	0.250	6.68	6.00	5.938	1:15.6	0.360	0.313	0.180	4⅜	44.25	14.75	2.57	14.02	4.67	1.45	0.45	107.51	S	3002-C
	8.30	0.313	7.06	6.00	6.000	1:15.6	0.360	0.313	0.180	4⅜	45.37	15.12	2.54	14.49	4.83	1.43	0.50	111.07		
	9.18	0.438	7.81	6.00	6.125	1:15.6	0.360	0.313	0.180	4⅜	47.62	15.87	2.47	15.49	5.16	1.41	0.62	118.64		3002-F
8x5	5.90	0.230	5.02	8.00	5.250	0	0.308	0.320	0	6¾	56.73	14.18	3.36	7.44	2.83	1.22	0.15	110.05	S	42100-E
8x7	8.32	0.245	7.08	8.00	6.500	0	0.398	0.400	0	6⅜	84.15	21.04	3.45	18.23	5.61	1.61	0.35	263.38	S	42100-F
8x8	10.72	0.288	9.12	8.00	8.000	0	0.433	0.400	0	6⅜	109.66	27.41	3.47	36.97	9.24	2.01	0.50	529.22	S	42100-G
	11.24	0.313	9.55	8.00	7.938	1:18.9	0.358	0.313	0.179	6¼	113.33	28.33	3.44	33.87	8.47	1.88	0.68	479.97	S	3002-D
	11.82	0.375	10.05	8.00	8.000	1:18.9	0.358	0.313	0.179	6¼	115.97	28.99	3.40	34.73	8.68	1.86	0.75	492.03		
	12.99	0.500	11.05	8.00	8.125	1:18.9	0.358	0.313	0.179	6¼	121.31	30.33	3.31	36.50	9.13	1.82	0.96	516.85	S	3002-E
10x5¾	7.30	0.240	6.21	9.90	5.750	0	0.340	0.312	0.031	8½	106.74	21.56	4.15	10.77	3.75	1.32	0.21	246.08	S	42100-J
10x8	11.41	0.292	9.71	9.75	7.964	0	0.433	0.500	0	7⅞	170.87	35.05	4.20	36.49	9.16	1.94	0.59	791.89	S	42100-K
12x8	13.84	0.294	11.77	11.94	8.000	0	0.516	0.600	0	9¾	310.10	51.94	5.13	44.08	11.02	1.94	0.97	1438.20	S	42100-L
12x10	18.34	0.345	15.59	12.06	10.000	0	0.576	0.600	0	9¾	426.20	70.68	5.23	96.07	19.21	2.48	1.61	3167.48	S	42100-M

①Classification "S" indicates standard structural shapes.

TABLE 44

Elements of Sections



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.

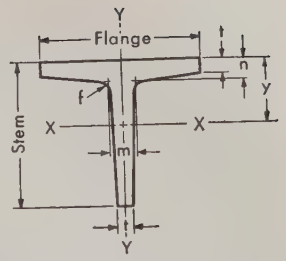
Size				Area	m	n	f	Axis X-X				Axis Y-Y			Classification① and Extrusion Section Numbers	
Flange	Stem	Weight	t					I	S	r	y	I	S	r		
1	1	0.31	1/8	0.27	5/32	5/32	1/8	0.023	0.032	0.293	0.292	0.011	0.023	0.206		853-F
1 1/2	1 1/4	0.44	1/8	0.37	5/32	5/32	1/8	0.049	0.053	0.363	0.326	0.038	0.051	0.319		853-B
	1 1/4	0.62	3/16	0.52	7/32	7/32	1/8	0.067	0.075	0.359	0.352	0.056	0.075	0.328		853-N
	1 1/2	0.68	3/16	0.58	7/32	7/32	3/16	0.114	0.108	0.433	0.437	0.056	0.075	0.312		853-K
	1 1/2	0.87	1/4	0.74	9/32	9/32	3/16	0.142	0.137	0.438	0.464	0.075	0.100	0.319		853-G
	2	0.86	3/16	0.73	1/4	1/4	3/16	0.269	0.195	0.606	0.624	0.060	0.080	0.286		853-W
2	2	1.26	1/4	1.07	5/16	5/16	1/4	0.37	0.26	0.59	0.58	0.18	0.18	0.41	S	853-C
	2	1.50	5/16	1.28	3/8	3/8	1/4	0.43	0.31	0.58	0.61	0.23	0.23	0.42		853-X
2 1/4	2 1/4	1.42	1/4	1.21	5/16	5/16	1/4	0.53	0.33	0.66	0.64	0.26	0.23	0.46	S	853-J
2 1/2	1 1/4	1.00	3/16	0.85	5/16	9/32	3/16	0.08	0.09	0.31	0.30	0.28	0.22	0.57		853-A
	2 1/2	1.91	5/16	1.62	3/8	3/8	1/4	0.89	0.50	0.74	0.73	0.44	0.35	0.52	S	853-M
	3	2.11	5/16	1.80	3/8	3/8	1/4	1.49	0.72	0.91	0.92	0.44	0.35	0.50		853-P

①Classification "S" indicates standard structural shapes.

Continued on next page

TABLE 44 [redacted] **Elements of Sections**

Concluded



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.

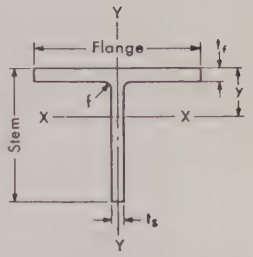
Size				Area	m	n	f	Axis X-X				Axis Y-Y			Classification① and Extrusion Section Numbers	
Flange	Stem	Weight	t					I	S	r	y	I	S	r		
3	2½	2.13	5/16	1.81	3/8	3/8	5/16	0.94	0.51	0.72	0.68	0.75	0.50	0.65		853-H
	3	2.33	5/16	1.98	3/8	3/8	5/16	1.58	0.74	0.89	0.85	0.75	0.50	0.62		853-Z
	3	2.72	3/8	2.31	7/16	7/16	5/16	1.83	0.86	0.89	0.88	0.90	0.60	0.63	S	853-D
4	2	2.70	3/8	2.30	7/16	7/16	1/4	0.60	0.40	0.51	0.48	2.10	1.05	0.96		853-L
	3	2.76	5/16	2.34	3/8	3/8	3/8	1.72	0.77	0.86	0.75	1.77	0.89	0.87		853-R
	4	3.74	3/8	3.18	7/16	7/16	1/2	4.56	1.58	1.20	1.11	2.12	1.06	0.82	S	853-E
	4½	3.98	3/8	3.39	7/16	7/16	1/2	6.37	1.98	1.37	1.29	2.13	1.06	0.79		
	5	4.22	3/8	3.59	7/16	7/16	1/2	8.56	2.43	1.54	1.48	2.13	1.06	0.77		853-S
	5	5.41	1/2	4.60	9/16	9/16	1/2	10.84	3.14	1.54	1.54	2.83	1.42	0.79		853-T
4½	3	2.96	5/16	2.52	3/8	3/8	3/8	1.78	0.78	0.84	0.71	2.52	1.12	1.00		853-O
5	3	4.02	3/8	3.42	5/8	7/16	3/8	2.37	1.06	0.83	0.76	4.13	1.65	1.10		853-Q

①Classification "S" indicates standard structural shapes.

TABLE 45

special tees

Elements of Sections



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

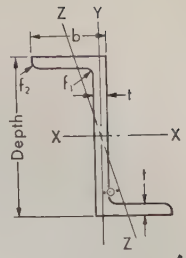
I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}

Size					Area	f	Axis X-X				Axis Y-Y			J	Extrusion Section Numbers
Flange	Stem	Weight	t_s	tf			I	S	r	y	I	S	r		
6	3	3.24	0.312	0.312	2.75	0.312	1.83	0.77	0.81	0.62	5.63	1.88	1.43	0.09	37526
	4	3.88	0.375	0.313	3.30	0.313	4.78	1.59	1.20	1.00	5.65	1.88	1.31	0.13	37524
	4	4.79	0.375	0.450	4.07	0.312	5.02	1.61	1.11	0.88	8.12	2.71	1.41	0.25	37525
	7.5	9.46	0.500	0.750	8.04	0.625	40.34	7.28	2.24	1.96	13.60	4.53	1.30	1.16	28084
	7.5	14.42	1.125	0.750	12.26	0.625	69.34	14.46	2.38	2.71	14.38	4.80	1.08	4.40	28232
8	6	11.24	0.500	0.860	9.56	0.500	22.93	4.82	1.55	1.24	36.76	9.19	1.96	1.95	37523

TABLE 46

Elements of Sections

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}
C_s = Torsion-bending Constant in in.^{6}



Size			Area	Actual Depth	b	f_1	f_2	Axis X-X			Axis Y-Y			Axis Z-Z			J	C_s	Classification① & Extrusion Section Numbers	
Nominal Depth	Weight	t						I	S	r	I	S	r	Θ	I	r				
1¾	1.08	3/16	0.92	1¾	1¾	3/16	1/8	0.446	0.510	0.695	0.551	0.333	0.773	48°49′	0.101	0.331	0.012	0.148		771-D
2	0.92	3/16	0.78	2	1¼	3/16	1/8	0.458	0.458	0.765	0.186	0.161	0.488	29°12′	0.063	0.283	0.010	0.079		771-C
2⅜	1.00	3/16	0.85	2⅜	1¼	3/16	1/8	0.694	0.584	0.902	0.186	0.161	0.467	23°12′	0.082	0.310	0.011	0.124		7088
3	2.33	¼	1.98	3	2 11/16	5/16	¼	2.89	1.92	1.21	2.64	1.03	1.15	43°24′	0.59	0.54	0.044	2.35	S	771-B
	3.38	⅜	2.87	3	2 11/16	5/16	¼	3.86	2.57	1.16	3.76	1.50	1.14	44°31′	0.82	0.53	0.15	2.83	S	771-A
	4.35	½	3.70	3	2 11/16	5/16	¼	4.60	3.06	1.11	4.71	1.93	1.13	45°27′	1.03	0.53	0.35	2.96		
4	2.85	¼②	2.42	4	3 1/16	5/16	¼	6.32	3.16	1.62	4.01	1.36	1.29	36°47′	1.08	0.67	0.053	7.20	S	771-J
	3.58	5/16	3.04	4 1/16	3⅛	5/16	¼	7.97	3.92	1.62	5.24	1.76	1.31	37°24′	1.39	0.68	0.10	9.15	S	771-M
	4.32	⅜③	3.67	4⅛	3 3/16	5/16	¼	9.66	4.68	1.62	6.54	2.18	1.33	37°55′	1.72	0.68	0.18	11.13	S	771-N
	4.78	7/16	4.06	4	3 1/16	5/16	¼	9.68	4.84	1.54	6.53	2.30	1.27	37°50′	1.74	0.66	0.28	9.75		771-G
	5.49	½	4.67	4 1/16	3⅛	5/16	¼	11.20	5.51	1.55	7.75	2.70	1.29	38°16′	2.06	0.66	0.43	11.26		
	6.22	9/16	5.29	4⅛	3 3/16	5/16	¼	12.76	6.19	1.55	9.05	3.11	1.31	38°41′	2.41	0.68	0.62	12.80		771-F
5	4.01	5/16	3.41	5	3¼	5/16	¼	13.41	5.36	1.98	5.94	1.92	1.32	30°40′	1.89	0.74	0.12	17.45		771-K
	4.84	⅜	4.12	5 1/16	3 5/16	5/16	¼	16.23	6.41	1.99	7.40	2.37	1.34	31°08′	2.33	0.75	0.21	21.30	S	771-E
	5.68	7/16	4.83	5⅛	3⅜	5/16	¼	19.12	7.46	1.99	8.95	2.84	1.36	31°32′	2.81	0.76	0.33	25.21		
	6.19	½	5.27	5	3¼	5/16	¼	19.23	7.69	1.91	8.82	2.94	1.29	31°09′	2.82	0.73	0.48	22.43	S	771-H
6	5.42	⅜	4.61	6	3½	5/16	¼	25.40	8.47	2.35	8.83	2.67	1.38	26°55′	3.08	0.82	0.23	38.55		
	7.29	½	6.20	6⅛	3⅝	5/16	¼	34.44	11.24	2.36	12.58	3.73	1.42	27°37′	4.36	0.84	0.56	52.94		
	9.72	11/16	8.27	6⅛	3⅝	5/16	¼	43.24	14.12	2.29	16.07	4.90	1.39	27°44′	5.70	0.83	1.45	60.02		771-L

①Classification "S" indicates standard structural shapes.

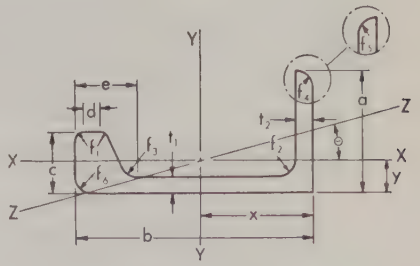
②Nominal rolled size in this web thickness is: depth 4 1/32″, flange width 3 1/32″.

③Nominal rolled size in this web thickness is: depth 4 5/32″, flange width 3 7/32″.

TABLE **47** bulb angles **Elements of Sections**

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.



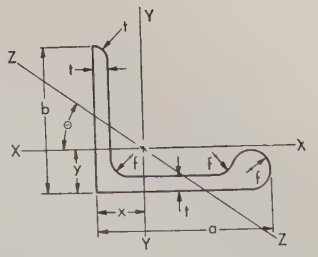
Size			Weight	Area	a	b	c	d	e	f_1	f_2	f_3	f_4	f_5	f_6	Axis X-X				Axis Y-Y				Axis Z-Z			Extrusion Section Numbers
Legs	t_1	t_2														I	S	r	y	I	S	r	x	θ	I	r	
4x3½	⅜	⅜	4.20	3.57	3.50	4.00	1.50	5/16	1¼	⅛	⅜	¼	3/16	0	⅜	3.02	1.18	0.92	0.93	7.95	3.58	1.49	1.78	20°13′	2.24	0.79	5022
5x2½	¼	¼	2.51	2.13	2.50	5.00	0.88	0	0.79	0.20	0.42	0.20	0	0.21	0.20	0.82	0.41	0.62	0.50	7.10	2.49	1.82	2.15	9°35′	0.64	0.55	32166
5x3½	⅜	⅜	4.63	3.92	3.50	5.00	1.50	1/16	1.17	3/16	⅜	3/16	¼	0	⅜	3.17	1.19	0.90	0.85	13.66	4.89	1.87	2.20	13°45′	2.50	0.80	37221
6x3½	0.28	0.31	3.70	3.14	3.51	6.01	1.06	0	0.97	0.24	0.54	0.24	0	0.27	0.24	2.70	0.98	0.93	0.74	15.44	4.33	2.22	2.44	13°21′	1.94	0.79	38669

TABLE 48 **Bulb angles** **Elements of Sections**

ARMY-NAVY SERIES

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I=Moment of Inertia in in.^{4}
S=Section Modulus in in.^{3}
r=Radius of Gyration in inches.



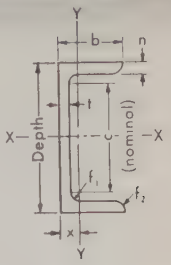
Size		Weight	Area	a	b	f	Axis X-X				Axis Y-Y				Axis Z-Z			Extrusion Section Numbers
Legs	t						I	S	r	y	I	S	r	x	θ	I	r	
1x3/4	0.063	0.149	0.127	1.00	0.750	0.095	0.006	0.010	0.221	0.157	0.016	0.026	0.354	0.379	20°42′	0.0046	0.190	10135-1002
1½x7/8	0.078	0.247	0.210	1.50	0.875	0.117	0.013	0.018	0.248	0.166	0.059	0.066	0.530	0.601	13°46′	0.0100	0.218	10135-1401
1¾x1¼	0.125	0.478	0.407	1.75	1.25	0.156	0.057	0.058	0.373	0.265	0.148	0.132	0.602	0.634	20°13′	0.0425	0.323	10135-1603
2x1	0.125	0.517	0.440	2.00	1.00	0.188	0.038	0.047	0.294	0.185	0.217	0.190	0.703	0.854	7°25′	0.0349	0.282	
2½x1½	0.188	0.995	0.846	2.50	1.50	0.250	0.173	0.144	0.453	0.298	0.643	0.425	0.872	0.986	11°07′	0.1546	0.427	
3x2	0.188	1.344	1.143	3.00	2.00	0.312	0.392	0.244	0.585	0.397	1.326	0.749	1.077	1.229	13°56′	0.3304	0.538	
3½x2½	0.250	2.068	1.758	3.50	2.50	0.375	0.982	0.495	0.747	0.517	2.715	1.271	1.243	1.364	16°25′	0.8174	0.682	

TABLE 49

channels

Elements of Sections

ARMY-NAVY SERIES



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}
C_s = Torsion-bending Constant in in.^{6}

Size			Area	b	n	f_1	f_2	c	Axis X-X			Axis Y-Y				J	C_s	Extrusion Section Numbers
Depth	Weight	t							I	S	r	I	S	r	x			
2.00	0.551	0.125	0.469	1.000	0.125	0.125	0.125	1½	0.270	0.270	0.758	0.040	0.057	0.294	0.284	0.0026	0.032	10137-2005
	0.856	0.156	0.728	1.500	0.156	0.125	0.156	1½	0.452	0.452	0.788	0.155	0.154	0.462	0.491	0.0063	0.114	10137-2010
	1.464	0.188	1.245	2.500	0.188	0.188	0.188	1¼	0.828	0.828	0.815	0.772	0.495	0.787	0.939	0.0155	0.498	10137-2013
2.50	0.625	0.125	0.531	1.000	0.125	0.125	0.125	2	0.461	0.369	0.932	0.043	0.058	0.285	0.258	0.0029	0.056	10137-2402
	0.901	0.156	0.767	1.375	0.156	0.125	0.156	2	0.711	0.569	0.963	0.130	0.134	0.412	0.403	0.0066	0.157	10137-2405
3.00	0.993	0.156	0.845	1.375	0.156	0.125	0.156	2½	1.098	0.732	1.140	0.138	0.138	0.404	0.373	0.0073	0.245	10137-3001
	1.354	0.188	1.151	1.750	0.188	0.188	0.188	2¼	1.553	1.036	1.162	0.322	0.262	0.529	0.521	0.0144	0.534	10137-3004
4.00	1.575	0.188	1.339	1.750	0.188	0.188	0.188	3¼	3.080	1.540	1.516	0.352	0.273	0.512	0.461	0.0166	1.083	
	2.205	0.250	1.875	2.000	0.250	0.250	0.250	3	4.313	2.156	1.517	0.647	0.452	0.588	0.568	0.0417	1.874	
5.00	1.810	0.188	1.539	1.750	0.188	0.250	0.188	4	5.268	2.107	1.850	0.375	0.281	0.493	0.415	0.0188	1.857	
	2.499	0.250	2.125	2.000	0.250	0.250	0.250	4	7.384	2.954	1.864	0.692	0.466	0.571	0.516	0.0469	3.251	
6.00	2.128	0.188	1.809	2.000	0.188	0.188	0.188	5¼	9.007	3.002	2.231	0.581	0.377	0.567	0.456	0.0221	4.119	
	2.940	0.250	2.500	2.250	0.250	0.250	0.250	5	12.538	4.179	2.239	1.031	0.608	0.642	0.555	0.0547	6.934	
7.00	3.611	0.188	3.070	3.000	0.312	0.188	0.188	6	25.019	7.148	2.855	3.032	1.471	0.994	0.939	0.0364	24.494	13827

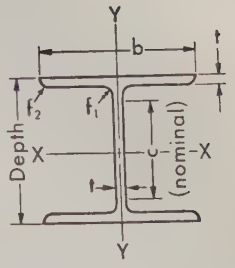
TABLE 50

wide-flange sections

ARMY-NAVY SERIES

Elements of Sections

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.[4]
S = Section Modulus in in.[3]
r = Radius of Gyration in inches.
J = Torsion Constant in in.[4]
C_s = Torsion-bending Constant in in.[6]



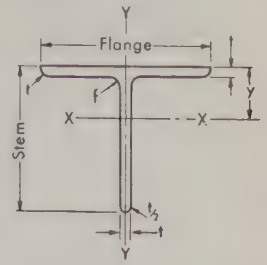
Size			Area	Actual Depth	b	f_1	f_2	c	Axis X-X			Axis Y-Y			J	C_s	Extrusion Section Numbers
Nominal Depth and Width	Weight	t							I	S	r	I	S	r			
2½x2	0.928	0.125	0.789	2.50	2.00	0.156	0.125	2	0.831	0.665	1.027	0.155	0.155	0.443	0.0050	0.218	10140-2402
3x2	1.001	0.125	0.851	3.00	2.00	0.156	0.125	2½	1.262	0.841	1.217	0.155	0.155	0.426	0.0054	0.320	10140-3002
4x2	1.139	0.125	0.969	4.00	2.00	0.125	0.125	3½	2.424	1.212	1.582	0.155	0.155	0.400	0.0063	0.581	10140-4003
4x3	1.788	0.156	1.521	4.00	3.00	0.188	0.156	3¼	4.136	2.068	1.649	0.659	0.439	0.658	0.0145	2.434	10140-4004
4x3½	3.060	0.250	2.602	4.00	3.50	0.188	0.250	3	6.968	3.484	1.637	1.638	0.936	0.793	0.0611	5.758	10140-4006
4x4½	2.867	0.188	2.438	4.00	4.50	0.312	0.125	3	7.091	3.545	1.706	2.786	1.238	1.069	0.0370	10.124	9242
5x5	5.366	0.312	4.563	5.00	5.00	0.312	0.125	3¾	19.683	7.873	2.077	6.444	2.578	1.188	0.1713	35.399	9430

TABLE 51

tees

Elements of Sections

ARMY-NAVY SERIES



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴
S = Section Modulus in in.³
r = Radius of Gyration in inches.
J = Torsion Constant in in.⁴

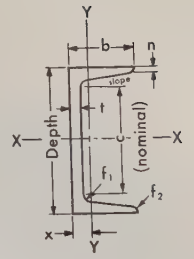
Size				Area	f	Axis X-X				Axis Y-Y			J	Extrusion Section Numbers
Flange	Stem	Weight	t			I	S	r	y	I	S	r		
1.50	1.25	0.384	0.125	0.326	0.125	0.045	0.049	0.371	0.327	0.032	0.043	0.314	0.0020	10136-1407
1.75	1.625	0.476	0.125	0.405	0.125	0.100	0.083	0.496	0.434	0.052	0.059	0.357	0.0024	10136-1608
2.00	1.00	0.421	0.125	0.358	0.125	0.025	0.032	0.266	0.212	0.078	0.078	0.466	0.0022	10136-2003
	1.75	0.531	0.125	0.451	0.125	0.128	0.098	0.532	0.451	0.078	0.078	0.415	0.0027	10136-2008
2.50	1.25	0.652	0.156	0.554	0.125	0.062	0.063	0.333	0.265	0.188	0.151	0.583	0.0051	10136-2403
	2.00	0.789	0.156	0.671	0.125	0.241	0.161	0.599	0.500	0.189	0.151	0.530	0.0060	10136-2408
3.00	2.00	0.881	0.156	0.749	0.125	0.254	0.164	0.582	0.456	0.330	0.220	0.663	0.0067	10136-3003
	2.50	1.170	0.188	0.995	0.188	0.565	0.302	0.753	0.632	0.393	0.262	0.629	0.0134	10136-3006
4.00	3.00	1.502	0.188	1.277	0.188	1.028	0.448	0.897	0.708	0.947	0.474	0.861	0.0167	
	4.00	2.271	0.250	1.931	0.250	2.978	1.021	1.242	1.084	1.239	0.619	0.801	0.0456	
	5.00	2.565	0.250	2.181	0.250	5.542	1.571	1.594	1.473	1.240	0.620	0.754	0.0508	

TABLE 52

special channels

Elements of Sections

All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.
J = Torsion Constant in in.^{4}
C_s = Torsion-bending Constant in in.^{6}



Size			Area	b	Slope	n	f_1	f_2	c	Axis X-X			Axis Y-Y				J	C_s	Classification① & Extrusion Section Numbers	
Depth	Weight	t								I	S	r	I	S	r	x				
2	1.22	0.170	1.04	1.410	1:6.0	0.170	0.270	0.100	¾	0.621	0.621	0.775	0.172	0.188	0.407	0.494	0.029	0.099		852-H
2½	1.24	0.250	1.06	1.250	1:6.0	0.125	0.250	0.125	1⅜	0.879	0.703	0.913	0.111	0.122	0.324	0.344	0.025	0.107		7400
3	2.24	0.250	1.90	2.000	1:12.1	0.250	0.250	0	1¾	2.61	1.74	1.17	0.68	0.52	0.60	0.68	0.068	0.90	S	5287
	2.70	0.375	2.30	2.000	0	0.375	0.188	0.375	1⅞	2.89	1.92	1.12	0.78	0.59	0.58	0.67	0.12	1.00	S	2229
4	3.32	0.318	2.82	2.500	1:34.9	0.313	0.375	0.125	2⅜	6.84	3.42	1.56	1.62	0.95	0.76	0.81	0.50	3.93	S	4885
5	3.10	0.188	2.64	2.875	1:10.7	0.188	0.250	0.094	3½	11.20	4.48	2.06	1.91	0.96	0.85	0.89	0.18	7.58		1351
	4.74	0.500	4.03	2.500	0	0.375	0.375	0.250	3½	13.37	5.35	1.82	1.94	1.08	0.69	0.71	0.30	7.54		1665
	5.82	0.438	4.95	2.875	1:9.8	0.438	0.250	0.094	3	18.13	7.25	1.91	3.57	1.87	0.85	0.96	0.55	12.97	S	1052
6	5.77	0.500	4.91	3.000	0	0.375	0.375	0.250	4½	24.05	8.02	2.21	3.52	1.61	0.85	0.81	0.36	20.35	S	1666
	5.93	0.375	5.04	3.500	1:49.6	0.412	0.480	0.420	4	28.22	9.41	2.37	5.58	2.31	1.05	1.09	0.32	31.21	S	2658
8	6.59	0.380	5.60	3.000	1:14.43	0.380	0.550	0.220	5¾	54.15	13.54	3.11	4.10	1.88	0.86	0.81	0.38	44.07	S	11866
	7.86	0.425	6.68	3.500	1:28.5	0.471	0.525	0.375	5¾	63.76	15.94	3.09	7.06	2.84	1.03	1.01	0.56	71.28	S	10005
10	8.58	0.375	7.30	3.500	1:9	0.375	0.625	0.188	7½	109.62	21.92	3.88	7.19	2.80	0.99	0.93	0.66	117.15	S	
	9.32	0.438	7.93	3.563	1:9	0.375	0.625	0.188	7½	114.87	22.97	3.81	7.73	2.93	0.99	0.92	0.78	126.12	S	
	10.05	0.500	8.55	3.625	1:9	0.375	0.625	0.188	7½	120.03	24.01	3.75	8.25	3.04	0.98	0.91	0.94	135.14	S	69780

①Classification "S" indicates standard structural shapes.

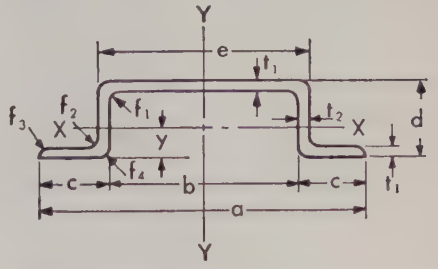
TABLE 53

wing channels

Elements of Sections

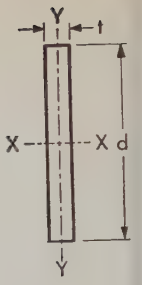
All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.



Size		Area	b	c	d	e	Thickness		f_1	f_2	f_3	f_4	Axis X-X				Axis Y-Y			Extrusion Section Numbers
Width, a	Weight						t_1	t_2					I	S	r	y	I	S	r	
3½	0.52	0.44	2 1/16	23/32	3/4	2 1/4	3/32	3/32	3/32	3/32	0	0	0.038	0.116	0.293	0.420	0.484	0.276	1.044	9004
4	0.77	0.66	1 3/4	1 1/8	3/4	2	1/8	1/8	1/8	1/8	1/8	0	0.054	0.139	0.288	0.359	0.804	0.402	1.107	7838
	0.90	0.76	1 3/4	1 1/8	1 1/8	2	1/8	1/8	1/8	3/16	1/32	0	0.148	0.251	0.440	0.533	0.946	0.473	1.112	4277
	1.14	0.97	1 5/16	1 11/32	2	1 1/2	5/32	3/32	1/8	0	1/8	0	0.603	0.517	0.789	0.833	0.980	0.490	1.006	8604
4¾	1.26	1.08	2	1 3/8	1 15/16	2 1/4	1/8	1/8	1/8	1/8	0	0	0.668	0.634	0.788	0.946	1.69	0.71	1.25	9498
5	1.12	0.95	2 3/4	1 1/8	1 1/2	3	1/8	1/8	1/8	3/16	0	0	0.339	0.485	0.597	0.803	1.97	0.79	1.44	4619
	1.85	1.57	1 5/8	1 11/16	1 7/8	2	3/16	3/16	1/8	1/4	1/8	0	0.778	0.709	0.704	0.778	2.53	1.01	1.27	5899
7½	4.83	4.11	2 1/8	2 11/16	3 3/8	2 3/4	5/16	5/16	1/8	1/8	0	7/16	6.28	3.15	1.24	1.38	13.66	3.64	1.82	5023

TABLE 54 rectangles **Elements of Sections**



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

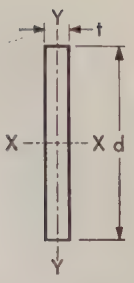
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
1	Wt.	0.147	0.221	0.294	0.368	0.441	0.514	0.588	0.662	0.735	0.882	1.029	1.176
	Area	0.125	0.188	0.250	0.313	0.375	0.438	0.500	0.563	0.625	0.750	0.875	1.000
	$I_{x\text{-}x}$	0.010	0.016	0.021	0.026	0.031	0.037	0.042	0.047	0.052	0.063	0.073	0.083
	$I_{y\text{-}y}$	0.000	0.001	0.001	0.003	0.004	0.007	0.010	0.015	0.020	0.035	0.056	0.083
1 1/8	Wt.	0.166	0.248	0.330	0.414	0.496	0.579	0.662	0.744	0.827	0.992	1.157	1.323
	Area	0.141	0.211	0.281	0.352	0.422	0.492	0.563	0.633	0.703	0.844	0.984	1.125
	$I_{x\text{-}x}$	0.015	0.022	0.030	0.037	0.045	0.052	0.059	0.067	0.074	0.089	0.104	0.119
	$I_{y\text{-}y}$	0.000	0.001	0.001	0.003	0.005	0.008	0.012	0.017	0.023	0.040	0.063	0.094
1 1/4	Wt.	0.184	0.276	0.378	0.459	0.551	0.643	0.735	0.827	0.919	1.102	1.287	1.470
	Area	0.156	0.234	0.313	0.391	0.469	0.547	0.625	0.703	0.781	0.938	1.094	1.250
	$I_{x\text{-}x}$	0.020	0.031	0.041	0.051	0.061	0.071	0.081	0.092	0.102	0.122	0.142	0.163
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.003	0.005	0.009	0.013	0.019	0.025	0.044	0.070	0.104
1 3/8	Wt.	0.202	0.303	0.405	0.506	0.607	0.708	0.809	0.909	1.010	1.212	1.415	1.617
	Area	0.172	0.258	0.344	0.430	0.516	0.602	0.688	0.773	0.859	1.031	1.203	1.375
	$I_{x\text{-}x}$	0.027	0.041	0.054	0.068	0.081	0.095	0.108	0.122	0.135	0.163	0.190	0.217
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.003	0.006	0.010	0.014	0.020	0.028	0.048	0.077	0.115
1 1/2	Wt.	0.220	0.331	0.441	0.551	0.662	0.772	0.882	0.992	1.102	1.323	1.544	1.764
	Area	0.188	0.281	0.375	0.469	0.563	0.656	0.750	0.844	0.938	1.125	1.313	1.500
	$I_{x\text{-}x}$	0.035	0.053	0.070	0.088	0.106	0.123	0.141	0.158	0.176	0.211	0.246	0.281
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.004	0.007	0.010	0.016	0.022	0.031	0.053	0.084	0.125
1 5/8	Wt.	0.239	0.359	0.477	0.597	0.716	0.836	0.956	1.075	1.195	1.434	1.672	1.911
	Area	0.203	0.305	0.406	0.508	0.609	0.711	0.813	0.914	1.016	1.219	1.422	1.625
	$I_{x\text{-}x}$	0.045	0.067	0.089	0.112	0.134	0.156	0.179	0.201	0.224	0.268	0.313	0.358
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.004	0.007	0.011	0.017	0.024	0.033	0.057	0.091	0.135
1 3/4	Wt.	0.257	0.386	0.514	0.643	0.772	0.900	1.029	1.158	1.286	1.544	1.800	2.058
	Area	0.219	0.328	0.438	0.547	0.656	0.766	0.875	0.984	1.094	1.313	1.531	1.750
	$I_{x\text{-}x}$	0.056	0.084	0.112	0.140	0.168	0.195	0.223	0.251	0.279	0.335	0.391	0.447
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.004	0.008	0.012	0.018	0.026	0.036	0.062	0.098	0.146
1 7/8	Wt.	0.275	0.414	0.512	0.689	0.827	0.964	1.103	1.241	1.378	1.653	1.930	2.205
	Area	0.234	0.352	0.469	0.586	0.703	0.820	0.938	1.055	1.172	1.406	1.641	1.875
	$I_{x\text{-}x}$	0.069	0.103	0.137	0.172	0.206	0.240	0.275	0.309	0.343	0.412	0.481	0.549
	$I_{y\text{-}y}$	0.000	0.001	0.002	0.005	0.008	0.013	0.020	0.028	0.038	0.066	0.105	0.156

TABLE 54

Rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

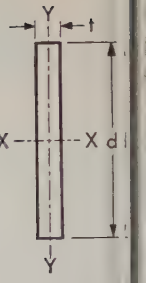
Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
2	Wt.	0.294	0.441	0.588	0.735	0.882	1.029	1.176	1.323	1.470	1.764	2.058	2.352
	Area	0.250	0.375	0.500	0.625	0.750	0.875	1.000	1.125	1.250	1.500	1.750	2.000
	$I_{x\text{-}x}$	0.083	0.125	0.167	0.208	0.250	0.292	0.333	0.375	0.417	0.500	0.583	0.667
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.005	0.009	0.014	0.021	0.030	0.041	0.070	0.112	0.167
2 1/8	Wt.	0.313	0.468	0.624	0.781	0.937	1.094	1.250	1.405	1.562	1.875	2.186	2.499
	Area	0.266	0.398	0.531	0.664	0.797	0.930	1.063	1.195	1.328	1.594	1.859	2.125
	$I_{x\text{-}x}$	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500	0.600	0.700	0.800
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.005	0.009	0.015	0.022	0.032	0.043	0.075	0.119	0.177
2 1/4	Wt.	0.331	0.496	0.662	0.827	0.992	1.158	1.323	1.488	1.654	1.984	2.316	2.646
	Area	0.281	0.422	0.563	0.703	0.844	0.984	1.125	1.266	1.406	1.688	1.969	2.250
	$I_{x\text{-}x}$	0.119	0.178	0.237	0.297	0.356	0.415	0.475	0.534	0.593	0.712	0.831	0.949
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.006	0.010	0.016	0.023	0.033	0.046	0.079	0.126	0.187
2 3/8	Wt	0.349	0.523	0.699	0.873	1.048	1.222	1.397	1.571	1.745	2.094	2.444	2.793
	Area	0.297	0.445	0.594	0.742	0.891	1.039	1.188	1.336	1.484	1.781	2.078	2.375
	$I_{x\text{-}x}$	0.140	0.209	0.279	0.349	0.419	0.488	0 558	0.628	0.698	0 837	0.977	1.116
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.006	0.010	0.017	0.025	0.035	0.048	0.083	0.133	0.198
2 1/2	Wt.	0.368	0.551	0.735	0.919	1.102	1.286	1.470	1.654	1.838	2.205	2.573	2.940
	Area	0.313	0.469	0.625	0.781	0.938	1.094	1.250	1.406	1.563	1.875	2.188	2.500
	$I_{x\text{-}x}$	0.163	0.244	0.326	0.407	0.488	0.570	0.651	0.732	0.814	0.977	1.139	1.302
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.006	0.011	0.017	0.026	0.037	0.051	0.088	0.140	0.208
2 5/8	Wt.	0.386	0.579	0.771	0.964	1.157	1.350	1.544	1.737	1.930	2.316	2.701	3.087
	Area	0.328	0.492	0.656	0.820	0.984	1.148	1.313	1.477	1.641	1.969	2.297	2.625
	$I_{x\text{-}x}$	0.188	0.283	0.377	0.471	0.565	0.660	0.754	0.848	0.942	1.131	1.319	1.507
	$I_{y\text{-}y}$	0.000	0.001	0.003	0.007	0.012	0.018	0.027	0.039	0.053	0.092	0.147	0.219
2 3/4	Wt.	0.404	0.606	0.808	1.011	1.213	1.415	1.617	1.819	2.021	2.426	2.829	3.234
	Area	0.344	0.516	0.688	0.859	1.031	1.203	1.375	1.547	1.719	2.063	2.406	2.750
	$I_{x\text{-}x}$	0.217	0.325	0.433	0.542	0.650	0.758	0.867	0.975	1.083	1.300	1.517	1.733
	$I_{y\text{-}y}$	0.000	0.002	0.004	0.007	0.012	0.019	0.029	0.041	0.056	0.097	0.154	0.229
2 7/8	Wt.	0.422	0.634	0.846	1.056	1.268	1.479	1.691	1.902	2.113	2.535	2.959	3.381
	Area	0.359	0.539	0.719	0.898	1.078	1.258	1.438	1.617	1.797	2.156	2.516	2.875
	$I_{x\text{-}x}$	0.248	0.371	0.495	0.619	0.743	0.866	0.990	1.114	1.238	1.485	1.733	1.980
	$I_{y\text{-}y}$	0.000	0.002	0.004	0.007	0.013	0.020	0.030	0.043	0.058	0.101	0.161	0.240

TABLE 54

rectangles

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2}, \quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d; \quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
3	Wt.	0.441	0.662	0.882	1.102	1.323	1.544	1.764	1.984	2.205	2.646	3.087	3.528
	Area	0.375	0.563	0.750	0.938	1.125	1.313	1.500	1.688	1.875	2.250	2.625	3.000
	$I_{x\text{-}x}$	0.281	0.422	0.563	0.703	0.844	0.984	1.125	1.266	1.406	1.688	1.969	2.250
	$I_{y\text{-}y}$	0.000	0.002	0.004	0.008	0.013	0.021	0.031	0.044	0.061	0.105	0.167	0.250
3 1/8	Wt.	0.460	0.689	0.918	1.149	1.378	1.608	1.838	2.067	2.297	2.757	3.215	3.675
	Area	0.391	0.586	0.781	0.977	1.172	1.367	1.563	1.758	1.953	2.344	2.734	3.125
	$I_{x\text{-}x}$	0.318	0.477	0.636	0.795	0.954	1.113	1.272	1.431	1.590	1.907	2.225	2.543
	$I_{y\text{-}y}$	0.001	0.002	0.004	0.008	0.014	0.022	0.033	0.046	0.064	0.110	0.174	0.260
3 1/4	Wt.	0.478	0.717	0.956	1.194	1.433	1.672	1.911	2.150	2.389	2.866	3.345	3.822
	Area	0.406	0.609	0.813	1.016	1.219	1.422	1.625	1.828	2.031	2.438	2.844	3.250
	$I_{x\text{-}x}$	0.358	0.536	0.715	0.894	1.073	1.252	1.430	1.609	1.788	2.146	2.503	2.861
	$I_{y\text{-}y}$	0.001	0.002	0.004	0.008	0.014	0.023	0.034	0.048	0.066	0.114	0.181	0.271
3 3/8	Wt.	0.496	0.744	0.992	1.241	1.488	1.737	1.985	2.323	2.480	2.976	3.473	3.969
	Area	0.422	0.633	0.844	1.055	1.266	1.477	1.688	1.898	2.109	2.531	2.953	3.375
	$I_{x\text{-}x}$	0.401	0.601	0.801	1.001	1.201	1.402	1.602	1.802	2.002	2.403	2.803	3.204
	$I_{y\text{-}y}$	0.001	0.002	0.004	0.009	0.015	0.024	0.035	0.050	0.069	0.119	0.188	0.281
3 1/2	Wt.	0.514	0.772	1.029	1.286	1.544	1.801	2.058	2.315	2.572	3.087	3.602	4.116
	Area	0.438	0.656	0.875	1.094	1.313	1.531	1.750	1.969	2.188	2.625	3.063	3.500
	$I_{x\text{-}x}$	0.447	0.670	0.893	1.117	1.340	1.563	1.787	2.010	2.233	2.680	3.126	3.573
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.009	0.015	0.024	0.036	0.052	0.071	0.123	0.195	0.292
3 5/8	Wt.	0.533	0.800	1.065	1.332	1.598	1.865	2.132	2.398	2.665	3.198	3.730	4.263
	Area	0.453	0.680	0.906	1.133	1.359	1.586	1.813	2.039	2.266	2.719	3.172	3.625
	$I_{x\text{-}x}$	0.496	0.744	0.992	1.241	1.489	1.737	1.985	2.233	2.481	2.977	3.473	3.970
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.009	0.016	0.025	0.038	0.054	0.074	0.127	0.202	0.302
3 3/4	Wt.	0.551	0.827	1.102	1.378	1.654	1.929	2.205	2.481	2.756	3.308	3.858	4.410
	Area	0.469	0.703	0.938	1.172	1.406	1.641	1.875	2.109	2.344	2.813	3.281	3.750
	$I_{x\text{-}x}$	0.549	0.824	1.099	1.373	1.648	1.923	2.197	2.472	2.747	3.296	3.845	4.395
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.010	0.016	0.026	0.039	0.056	0.076	0.132	0.209	0.312
3 7/8	Wt.	0.569	0.855	1.139	1.424	1.709	1.993	2.279	2.564	2.848	3.417	3.988	4.557
	Area	0.484	0.727	0.969	1.211	1.453	1.695	1.938	2.180	2.422	2.906	3.391	3.875
	$I_{x\text{-}x}$	0.606	0.909	1.212	1.515	1.818	2.121	2.424	2.728	3.031	3.637	4.243	4.849
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.010	0.017	0.027	0.040	0.057	0.079	0.136	0.216	0.323

TABLE 54 rectangles **Elements of Sections**

Continued

All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}

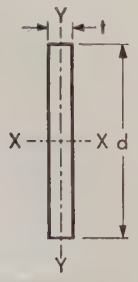
Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2}; \quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

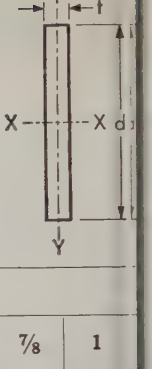
$$r_{x\text{-}x}=0.289\ d; \quad r_{y\text{-}y}=0.289\ t$$



Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
4	Wt.	0.588	0.882	1.176	1.470	1.764	2.058	2.352	2.646	2.940	3.528	4.116	4.704
	Area	0.500	0.750	1.000	1.250	1.500	1.750	2.000	2.250	2.500	3.000	3.500	4.000
	$I_{x\text{-}x}$	0.667	1.000	1.333	1.667	2.000	2.333	2.667	3.000	3.333	4.000	4.667	5.333
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.010	0.018	0.028	0.042	0.059	0.081	0.141	0.223	0.333
4 1/8	Wt.	0.607	0.909	1.212	1.516	1.819	2.123	2.426	2.728	3.032	3.639	4.244	4.851
	Area	0.516	0.773	1.031	1.289	1.547	1.805	2.063	2.320	2.578	3.094	3.609	4.125
	$I_{x\text{-}x}$	0.731	1.097	1.462	1.828	2.193	2.559	2.925	3.290	3.656	4.387	5.118	5.849
	$I_{y\text{-}y}$	0.001	0.002	0.005	0.010	0.018	0.029	0.043	0.061	0.084	0.145	0.230	0.344
4 1/4	Wt.	0.625	0.937	1.250	1.562	1.874	2.187	2.499	2.811	3.124	3.748	4.374	4.998
	Area	0.531	0.797	1.063	1.328	1.594	1.859	2.125	2.391	2.656	3.188	3.719	4.250
	$I_{x\text{-}x}$	0.800	1.200	1.599	1.999	2.399	2.799	3.199	3.598	3.998	4.798	5.598	6.397
	$I_{y\text{-}y}$	0.001	0.002	0.006	0.011	0.019	0.030	0.044	0.063	0.086	0.149	0.237	0.354
4 3/8	Wt.	0.643	0.964	1.287	1.608	1.930	2.251	2.573	2.894	3.215	3.858	4.502	5.145
	Area	0.547	0.820	1.094	1.367	1.641	1.914	2.188	2.461	2.734	3.281	3.828	4.375
	$I_{x\text{-}x}$	0.872	1.308	1.745	2.181	2.617	3.053	3.489	3.925	4.362	5.234	6.106	6.978
	$I_{y\text{-}y}$	0.001	0.002	0.006	0.011	0.019	0.031	0.046	0.065	0.089	0.154	0.244	0.365
4 1/2	Wt.	0.662	0.992	1.323	1.654	1.984	2.315	2.646	2.977	3.308	3.969	4.631	5.292
	Area	0.563	0.844	1.125	1.406	1.688	1.969	2.250	2.531	2.813	3.375	3.938	4.500
	$I_{x\text{-}x}$	0.949	1.424	1.898	2.373	2.848	3.322	3.797	4.272	4.746	5.695	6.645	7.594
	$I_{y\text{-}y}$	0.001	0.002	0.006	0.011	0.020	0.031	0.047	0.067	0.092	0.158	0.251	0.375
4 5/8	Wt.	0.680	1.020	1.360	1.700	2.039	2.380	2.720	3.060	3.400	4.079	4.759	5.439
	Area	0.578	0.867	1.156	1.445	1.734	2.023	2.313	2.602	2.891	3.469	4.047	4.625
	$I_{x\text{-}x}$	1.031	1.546	2.061	2.576	3.092	3.607	4.122	4.637	5.153	6.183	7.214	8.244
	$I_{y\text{-}y}$	0.001	0.003	0.006	0.012	0.020	0.032	0.048	0.069	0.094	0.163	0.258	0.385
4 3/4	Wt.	0.698	1.047	1.396	1.746	2.095	2.444	2.793	3.142	3.491	4.190	4.887	5.586
	Area	0.594	0.891	1.188	1.484	1.781	2.078	2.375	2.672	2.969	3.563	4.156	4.750
	$I_{x\text{-}x}$	1.116	1.675	2.233	2.791	3.349	3.907	4.466	5.024	5.582	6.698	7.815	8.931
	$I_{y\text{-}y}$	0.001	0.003	0.006	0.012	0.021	0.033	0.049	0.070	0.097	0.167	0.265	0.396
4 7/8	Wt.	0.716	1.075	1.434	1.791	2.150	2.508	2.867	3.225	3.583	4.299	5.017	5.733
	Area	0.609	0.914	1.219	1.523	1.828	2.133	2.438	2.742	3.047	3.656	4.266	4.875
	$I_{x\text{-}x}$	1.207	1.810	2.414	3.017	3.621	4.224	4.827	5.431	6.034	7.241	8.448	9.655
	$I_{y\text{-}y}$	0.001	0.003	0.006	0.012	0.021	0.034	0.051	0.072	0.099	0.171	0.272	0.406

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.^{4}

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\,x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

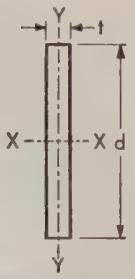
Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
5	Wt.	0.735	1.102	1.470	1.838	2.205	2.572	2.940	3.308	3.675	4.410	5.145	5.880
	Area	0.625	0.938	1.250	1.563	1.875	2.188	2.500	2.813	3.125	3.750	4.375	5.000
	$I_{x\text{-}x}$	1.302	1.953	2.604	3.255	3.906	4.557	5.208	5.859	6.510	7.813	9.115	10.42
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.013	0.022	0.035	0.052	0.074	0.102	0.176	0.279	0.417
5 1/8	Wt.	0.754	1.130	1.506	1.884	2.260	2.637	3.014	3.390	3.767	4.521	5.273	6.027
	Area	0.641	0.961	1.281	1.602	1.922	2.242	2.563	2.883	3.203	3.844	4.484	5.125
	$I_{x\text{-}x}$	1.402	2.103	2.804	3.506	4.207	4.908	5.609	6.310	7.011	8.413	9.815	11.22
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.013	0.023	0.036	0.053	0.076	0.104	0.180	0.286	0.427
5 1/4	Wt.	0.772	1.158	1.544	1.929	2.315	2.701	3.087	3.473	3.859	4.630	5.402	6.174
	Area	0.656	0.984	1.313	1.641	1.969	2.297	2.625	2.953	3.281	3.938	4.594	5.250
	$I_{x\text{-}x}$	1.507	2.261	3.015	3.768	4.522	5.276	6.029	6.783	7.537	9.044	10.55	12.06
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.013	0.023	0.037	0.055	0.078	0.107	0.185	0.293	0.437
5 3/8	Wt.	0.790	1.185	1.581	1.976	2.371	2.766	3.161	3.555	3.950	4.740	5.531	6.321
	Area	0.672	1.008	1.344	1.680	2.016	2.352	2.688	3.023	3.359	4.031	4.703	5.375
	$I_{x\text{-}x}$	1.618	2.426	3.235	4.044	4.853	5.662	6.470	7.279	8.088	9.705	11.32	12.94
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.014	0.024	0.038	0.056	0.080	0.109	0.189	0.300	0.448
5 1/2	Wt.	0.808	1.213	1.617	2.021	2.426	2.830	3.234	3.638	4.042	4.851	5.660	6.468
	Area	0.688	1.031	1.375	1.719	2.063	2.406	2.750	3.094	3.438	4.125	4.813	5.500
	$I_{x\text{-}x}$	1.733	2.600	3.466	4.333	5.199	6.066	6.932	7.799	8.665	10.40	12.13	13.86
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.014	0.024	0.038	0.057	0.082	0.112	0.193	0.307	0.458
5 5/8	Wt.	0.827	1.241	1.653	2.067	2.480	2.894	3.308	3.721	4.135	4.962	5.788	6.615
	Area	0.703	1.055	1.406	1.758	2.109	2.461	2.813	3.164	3.516	4.219	4.992	5.625
	$I_{x\text{-}x}$	1.854	2.781	3.708	4.635	5.562	6.489	7.416	8.343	9.270	11.12	12.98	14.83
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.014	0.025	0.039	0.059	0.083	0.114	0.198	0.314	0.469
5 3/4	Wt.	0.845	1.268	1.690	2.113	2.536	2.958	3.381	3.804	4.226	5.072	5.916	6.762
	Area	0.719	1.078	1.438	1.797	2.156	2.516	2.875	3.234	3.594	4.313	5.031	5.750
	$I_{x\text{-}x}$	1.980	2.971	3.961	4.951	5.941	6.931	7.921	8.911	9.902	11.88	13.86	15.84
	$I_{y\text{-}y}$	0.001	0.003	0.007	0.015	0.025	0.040	0.060	0.085	0.117	0.202	0.321	0.479
5 7/8	Wt.	0.863	1.296	1.728	2.159	2.591	3.022	3.455	3.887	4.318	5.181	6.046	6.909
	Area	0.734	1.102	1.469	1.836	2.203	2.570	2.938	3.305	3.672	4.406	5.141	5.875
	$I_{x\text{-}x}$	2.112	3.168	4.225	5.281	6.337	7.393	8.449	9.505	10.56	12.67	14.79	16.90
	$I_{y\text{-}y}$	0.001	0.003	0.008	0.015	0.026	0.041	0.061	0.087	0.120	0.207	0.328	0.490

TABLE 54

rectangles

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

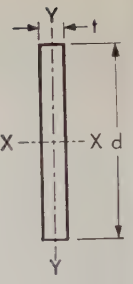
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
6	Wt.	0.882	1.323	1.764	2.205	2.646	3.087	3.528	3.969	4.410	5.292	6.174	7.056
	Area	0.750	1.125	1.500	1.875	2.250	2.625	3.000	3.375	3.750	4.500	5.250	6.000
	$I_{x\text{-}x}$	2.250	3.375	4.500	5.625	6.750	7.875	9.000	10.13	11.25	13.50	15.75	18.00
	$I_{y\text{-}y}$	0.001	0.003	0.008	0.015	0.026	0.042	0.063	0.089	0.122	0.211	0.335	0.500
6 1/8	Wt.	0.901	1.350	1.800	2.251	2.701	3.152	3.602	4.051	4.502	5.403	6.302	7.203
	Area	0.766	1.148	1.531	1.914	2.297	2.680	3.063	3.445	3.828	4.594	5.359	6.125
	$I_{x\text{-}x}$	2.394	3.590	4.787	5.984	7.181	8.378	9.574	10.77	11.97	14.36	16.76	19.15
	$I_{y\text{-}y}$	0.001	0.003	0.008	0.016	0.027	0.043	0.064	0.091	0.125	0.215	0.342	0.510
6 1/4	Wt.	0.919	1.378	1.838	2.297	2.756	3.216	3.675	4.134	4.594	5.512	6.432	7.350
	Area	0.781	1.172	1.563	1.953	2.344	2.734	3.125	3.516	3.906	4.688	5.469	6.250
	$I_{x\text{-}x}$	2.543	3.815	5.086	6.358	7.629	8.901	10.17	11.44	12.72	15.26	17.80	20.35
	$I_{y\text{-}y}$	0.001	0.003	0.008	0.016	0.027	0.044	0.065	0.093	0.127	0.220	0.349	0.521
6 3/8	Wt.	0.937	1.405	1.875	2.343	2.812	3.280	3.749	4.217	4.685	5.622	6.560	7.497
	Area	0.797	1.195	1.594	1.992	2.391	2.789	3.188	3.586	3.984	4.781	5.578	6.375
	$I_{x\text{-}x}$	2.699	4.048	5.398	6.747	8.096	9 446	10.80	12.14	13.49	16.19	18.89	21.59
	$I_{y\text{-}y}$	0.001	0.004	0.008	0.016	0.028	0.044	0.066	0.095	0.130	0.224	0.356	0.531
6 1/2	Wt.	0.956	1.433	1.911	2.389	2.866	3.344	3.822	4.300	4.778	5.733	6.689	7.644
	Area	0.813	1.219	1.625	2.031	2.438	2.844	3.250	3.656	4.063	4.875	5.688	6.500
	$I_{x\text{-}x}$	2.861	4.291	5.721	7.152	8.582	10.01	11.44	12.87	14.30	17.16	20.02	22.89
	$I_{y\text{-}y}$	0.001	0.004	0.008	0.017	0.029	0.045	0.068	0.096	0.132	0.229	0.363	0.542
6 5/8	Wt.	0.974	1.461	1.947	2.434	2.921	3.408	3.896	4.383	4.870	5.844	6.817	7.791
	Area	0.828	1.242	1.656	2.070	2.484	2.898	3.313	3.727	4.141	4.969	5.797	6.625
	$I_{x\text{-}x}$	3.029	4.543	6.058	7.572	9.087	10.60	12.12	13.63	15.14	18.17	21.20	24.23
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.017	0.029	0.046	0.069	0.098	0.135	0.233	0.370	0.552
6 3/4	Wt.	0.992	1.488	1.984	2.481	2.977	3.473	3.969	4.465	4.961	5.953	6.945	7.938
	Area	0.844	1.266	1.688	2.109	2.531	2.953	3.375	3.797	4.219	5.063	5.906	6.750
	$I_{x\text{-}x}$	3.204	4.805	6.407	8.009	9.611	11.21	12.81	14.42	16.02	19.22	22.43	25.63
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.017	0.030	0.047	0.070	0.100	0.137	0.237	0.377	0.562
6 7/8	Wt.	1.010	1.516	2.022	2.526	3.032	3.537	4.043	4.508	5.053	6.063	7.075	8.085
	Area	0.859	1.289	1.719	2.148	2.578	3.008	3.438	3.867	4.297	5.156	6.016	6.875
	$I_{x\text{-}x}$	3.385	5.077	6.770	8.462	10.15	11.85	13.54	15.23	16.92	20.31	23.69	27.08
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.017	0.030	0.048	0.072	0.102	0.140	0.242	0.384	0.573

TABLE
54

[redacted] **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

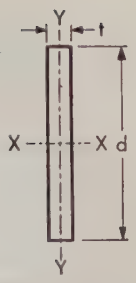
Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
7	Wt.	1.029	1.543	2.058	2.572	3.087	3.602	4.116	4.630	5.145	6.147	7.203	8.232
	Area	0.875	1 313	1.750	2.188	2.625	3.063	3.500	3.938	4.375	5.250	6.125	7.000
	$I_{x\text{-}x}$	3.573	5.359	7.146	8.932	10.72	12.51	14.29	16.08	17.86	21.44	25.01	28.58
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.018	0.031	0.049	0.073	0.104	0.142	0.246	0.391	0.583
7 1/8	Wt.	1.048	1.571	2.094	2.619	3.142	3.666	4.190	4.713	5.237	6.285	7.331	8.379
	Area	0.891	1.336	1.781	2.227	2.672	3.117	3.563	4.008	4.453	5.344	6.234	7.125
	$I_{x\text{-}x}$	3.768	5.652	7.536	9.419	11.30	13 19	15.07	16.95	18.84	22.61	26.37	30.14
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.018	0.031	0.050	0.074	0.106	0.145	0.250	0.398	0.594
7 1/4	Wt.	1.066	1.599	2.132	2.664	3.197	3.732	4.263	4.796	5.329	6.394	7.461	8.526
	Area	0.906	1.359	1.813	2.266	2.719	3.172	3.625	4.078	4.531	5.438	6.344	7.250
	$I_{x\text{-}x}$	3.970	5.954	7.939	9.924	11.91	13.89	15.88	17.86	19.85	23.82	27.79	31.76
	$I_{y\text{-}y}$	0.001	0.004	0.009	0.018	0.032	0.051	0.076	0.108	0.148	0.255	0.405	0.604
7 3/8	Wt.	1.084	1.626	2.169	2.711	3.253	3.795	4.337	4.878	5.420	6.504	7.589	8.673
	Area	0.922	1.383	1.844	2.305	2.766	3.227	3.688	4.148	4.609	5.531	6.453	7.375
	$I_{x\text{-}x}$	4.178	6.268	8.357	10.45	12.54	14.62	16.71	18.80	20.89	25.07	29.25	33.43
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.019	0.032	0.051	0.077	0.109	0.150	0.259	0.412	0.615
7 1/2	Wt.	1.102	1.654	2.205	2.756	3.308	3.859	4.411	4.961	5.512	6.150	7.718	8.820
	Area	0.938	1.406	1.875	2.344	2.813	3.281	3.750	4.219	4.688	5.625	6.563	7.500
	$I_{x\text{-}x}$	4.395	6.592	8.789	10.99	13.18	15.38	17.58	19.78	21.97	26.37	30.76	35.16
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.019	0.033	0.052	0.078	0.111	0.153	0.264	0.419	0.625
7 5/8	Wt.	1.121	1.682	2.241	2.802	3.362	3.923	4.484	5.044	5.605	6.726	7.846	8.967
	Area	0.953	1.430	1.906	2.383	2.859	3.336	3.813	4.289	4.766	5.719	6.672	7.625
	$I_{x\text{-}x}$	4.618	6.927	9.236	11.54	13.85	16.16	18.47	20.78	23.09	27.71	32.33	36.94
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.019	0.034	0.053	0.079	0.113	0.155	0.268	0.426	0.635
7 3/4	Wt.	1.139	1.709	2.278	2.848	3.418	3.987	4.557	5.127	5.696	6.835	7.974	9.114
	Area	0.969	1.453	1.938	2.422	2.906	3.391	3.875	4.359	4.844	5.813	6.781	7.750
	$I_{x\text{-}x}$	4.849	7.273	9.698	12.12	14.55	16.97	19.40	21.82	24.24	29.09	33.94	38.79
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.020	0.034	0.054	0.081	0.115	0.158	0.272	0.433	0.646
7 7/8	Wt.	1.157	1.737	2.316	2.894	3.473	4.051	4.631	5.210	5.788	6.945	8.104	9.261
	Area	0.984	1.477	1.969	2.461	2.953	3.445	3.938	4.430	4.922	5.906	6.891	7.875
	$I_{x\text{-}x}$	5.087	7.631	10.17	12.72	15.26	17.81	20.35	22.89	25.44	30.52	35.61	40.70
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.020	0.035	0.055	0.082	0.117	0.160	0.277	0.440	0.656

TABLE 54

rectangles

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

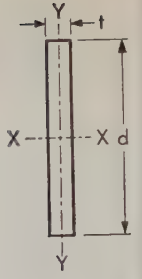
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
8	Wt.	1.176	1.764	2.352	2.940	3.528	4.116	4.704	5.292	5.880	7.056	8.232	9.408
	Area	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000	6.000	7.000	8.000
	$I_{x\text{-}x}$	5.333	8.000	10.67	13.33	16.00	18.67	21.33	24.00	26.67	32.00	37.33	42.67
	$I_{y\text{-}y}$	0.001	0.004	0.010	0.020	0.035	0.056	0.083	0.119	0.163	0.281	0.447	0.667
8 1/8	Wt.	1.195	1.791	2.388	2.986	3.583	4.181	4.778	5.374	5.972	7.167	8.360	9.555
	Area	1.016	1.523	2.031	2.539	3.047	3.555	4.063	4.570	5.078	6.094	7.109	8.125
	$I_{x\text{-}x}$	5.587	8.381	11.17	13.97	16.76	19.56	22.35	25.14	27.94	33.52	39.11	44.70
	$I_{y\text{-}y}$	0.001	0.004	0.011	0.021	0.036	0.057	0.085	0.121	0.165	0.286	0.454	0.677
8 1/4	Wt.	1.213	1.819	2.426	3.032	3.638	4.245	4.851	5.457	6.064	7.276	8.490	9.702
	Area	1.031	1.547	2.063	2.578	3.094	3.609	4.125	4.641	5.156	6.188	7.219	8.250
	$I_{x\text{-}x}$	5.849	8.774	11.70	14.62	17.55	20.47	23.40	26.32	29.25	35.09	40.94	46.79
	$I_{y\text{-}y}$	0.001	0.005	0.011	0.021	0.036	0.058	0.086	0.122	0.168	0.290	0.461	0.687
8 3/8	Wt.	1.231	1.846	2.463	3.078	3.694	4.309	4.925	5.540	6.155	7.386	8.618	9.849
	Area	1.047	1.570	2.094	2.617	3.141	3.664	4.188	4.711	5.234	6.281	7.328	8.375
	$I_{x\text{-}x}$	6.119	9.179	12.24	15.30	18.36	21.42	24.48	27.54	30.60	36.71	42.83	48.95
	$I_{y\text{-}y}$	0.001	0.005	0.011	0.021	0.037	0.058	0.087	0.124	0.170	0.294	0.468	0.698
8 1/2	Wt.	1.250	1.874	2.499	3.124	3.748	4.373	4.998	5.623	6.248	7.497	8.747	9.996
	Area	1.063	1.594	2.125	2.656	3.188	3.719	4.250	4.781	5.313	6.375	7.438	8.500
	$I_{x\text{-}x}$	6.397	9.596	12.79	15.99	19.19	22.39	25.59	28.79	31.99	38.38	44.78	51.18
	$I_{y\text{-}y}$	0.001	0.005	0.011	0.022	0.037	0.059	0.089	0.126	0.173	0.299	0.475	0.708
8 5/8	Wt.	1.268	1.902	2.535	3.169	3.803	4.437	5.072	5.706	6.340	7.608	8.875	10.14
	Area	1.078	1.617	2.156	2.695	3.234	3.773	4.313	4.852	5.391	6.469	7.547	8.625
	$I_{x\text{-}x}$	6.684	10.03	13.37	16.71	20.05	23.39	26.73	30.08	33.42	40.10	46.78	53.47
	$I_{y\text{-}y}$	0.001	0.005	0.011	0.022	0.038	0.060	0.090	0.128	0.175	0.303	0.482	0.719
8 3/4	Wt.	1.286	1.929	2.572	3.216	3.859	4.502	5.145	5.788	6.431	7.718	9.003	10.29
	Area	1.094	1.641	2.188	2.734	3.281	3.828	4.375	4.922	5.469	6.563	7.656	8.750
	$I_{x\text{-}x}$	6.978	10.47	13.96	17.45	20.94	24.42	27.91	31.40	34.89	41.87	48.85	55.83
	$I_{y\text{-}y}$	0.001	0.005	0.011	0.022	0.038	0.061	0.091	0.130	0.178	0.308	0.488	0.729
8 7/8	Wt.	1.304	1.957	2.610	3.261	3.914	4.566	5.219	5.871	6.523	7.827	9.133	10.44
	Area	1.109	1.664	2.219	2.773	3.328	3.883	4.438	4.992	5.547	6.656	7.766	8.875
	$I_{x\text{-}x}$	7.282	10.92	14.56	18.20	21.85	25.49	29.13	32.77	36.41	43.69	50.97	58.25
	$I_{y\text{-}y}$	0.001	0.005	0.012	0.023	0.039	0.062	0.092	0.132	0.181	0.312	0.495	0.740

TABLE 54

rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

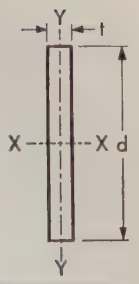
Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
9	Wt.	1.323	1.984	2.646	3.308	3.969	4.630	5.292	5.954	6.615	7.938	9.261	10.58
	Area	1.125	1.688	2.250	2.813	3.375	3.938	4.500	5.063	5.625	6.750	7.875	9.000
	$I_{x\text{-}x}$	7.594	11.39	15.19	18.98	22.78	26.58	30.38	34.17	37.97	45.56	53.16	60.75
	$I_{y\text{-}y}$	0.001	0.005	0.012	0.023	0.040	0.063	0.094	0.133	0.183	0.316	0.502	0.750
9 1/8	Wt.	1.342	2.012	2.682	3.354	4.024	4.695	5.366	6.036	6.707	8.049	9.389	10.73
	Area	1.141	1.711	2.281	2.852	3.422	3.992	4.563	5.133	5.703	6.844	7.984	9.125
	$I_{x\text{-}x}$	7.915	11.87	15.83	19.79	23.74	27.70	31.66	35.62	39.57	47.49	55.40	63.32
	$I_{y\text{-}y}$	0.001	0.005	0.012	0.023	0.040	0.064	0.095	0.135	0.186	0.321	0.509	0.760
9 1/4	Wt.	1.360	2.040	2.720	3.399	4.079	4.759	5.439	6.119	6.799	8.158	9.519	10.88
	Area	1.156	1.734	2.313	2.891	3.469	4.047	4.625	5.203	5.781	6.938	8.094	9.250
	$I_{x\text{-}x}$	8.244	12.37	16.49	20.61	24.73	28.86	32.98	37.10	41.22	49.47	57.71	65.95
	$I_{y\text{-}y}$	0.002	0.005	0.012	0.024	0.041	0.065	0.096	0.137	0.188	0.325	0.516	0.771
9 3/8	Wt.	1.378	2.067	2.757	3.446	4.135	4.824	5.513	6.201	6.890	8.268	9.647	10.25
	Area	1.172	1.758	2.344	2.930	3.516	4.102	4.688	5.273	5.859	7.031	8.203	9.375
	$I_{x\text{-}x}$	8.583	12.87	17.17	21.46	25.75	30.04	34.33	38.62	42.92	51.50	60.08	68.66
	$I_{y\text{-}y}$	0.002	0.005	0.012	0.024	0.041	0.065	0.098	0.139	0.191	0.330	0.523	0.781
9 1/2	Wt.	1.396	2.095	2.793	3.491	4.190	4.888	5.586	6.284	6.982	8.379	9.776	11.17
	Area	1.188	1.781	2.375	2.969	3.563	4.156	4.750	5.344	5.938	7.125	8.313	9.500
	$I_{x\text{-}x}$	8.931	13.40	17.86	22.33	26.79	31.26	35.72	40.19	44.66	53.59	62.52	71.45
	$I_{y\text{-}y}$	0.002	0.005	0.012	0.024	0.042	0.066	0.099	0.141	0.193	0.334	0.530	0.792
9 5/8	Wt.	1.415	2.123	2.829	3.537	4.244	4.952	5.660	6.367	7.075	8.490	9.904	11.32
	Area	1.203	1.805	2.406	3.008	3.609	4.211	4.813	5.414	6.016	7.219	8.422	9.625
	$I_{x\text{-}x}$	9.288	13.93	18.58	23.22	27.86	32.51	37.15	41.80	46.44	55.73	65.02	74.31
	$I_{y\text{-}y}$	0.002	0.005	0.013	0.024	0.042	0.067	0.100	0.143	0.196	0.338	0.537	0.802
9 3/4	Wt.	1.433	2.150	2.866	3.583	4.300	5.016	5.733	6.450	7.166	8.600	10.03	11.47
	Area	1.219	1.828	2.438	3.047	3.656	4.266	4.875	5.484	6.094	7.313	8.531	9.750
	$I_{x\text{-}x}$	9.655	14.48	19.31	24.14	28.96	33.79	38.62	43.45	48.27	57.93	67.58	77.24
	$I_{y\text{-}y}$	0.002	0.005	0.013	0.025	0.043	0.068	0.102	0.145	0.198	0.343	0.544	0.812
9 7/8	Wt.	1.451	2.178	2.904	3.629	4.355	5.080	5.807	6.533	7.258	8.709	10.16	11.61
	Area	1.234	1.852	2.469	3.086	3.703	4.320	4.938	5.555	6.172	7.406	8.641	9.875
	$I_{x\text{-}x}$	10.03	15.05	20.06	25.08	30.09	35.11	40.12	45.14	50.15	60.19	70.22	80.25
	$I_{y\text{-}y}$	0.002	0.005	0.013	0.025	0.043	0.069	0.103	0.146	0.201	0.347	0.551	0.823

TABLE 54

rectangles

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

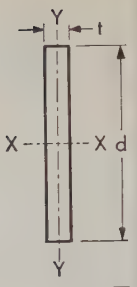
Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
10	Wt.	1.470	2.205	2.940	3.675	4.411	5.145	5.880	6.615	7.350	8.820	10.29	11.76
	Area	1.250	1.875	2.500	3.125	3.750	4.375	5.000	5.625	6.250	7.500	8.750	10.00
	$I_{x\text{-}x}$	10.42	15.63	20.83	26.04	31.25	36.46	41.67	46.88	52.08	62.50	72.92	83.33
	$I_{y\text{-}y}$	0.002	0.005	0.013	0.025	0.044	0.070	0.104	0.148	0.203	0.352	0.558	0.833
10 1/8	Wt.	1.489	2.232	2.976	3.721	4.465	5.210	5.954	6.697	7.442	8.931	10.42	11.91
	Area	1.266	1.898	2.531	3.164	3.797	4.430	5.063	5.695	6.328	7.594	8.859	10.13
	$I_{x\text{-}x}$	10.81	16.22	21.62	27.03	32.44	37.84	43.25	48.65	54.06	64.87	75.69	86.50
	$I_{y\text{-}y}$	0.002	0.006	0.013	0.026	0.044	0.071	0.105	0.150	0.206	0.356	0.565	0.844
10 1/4	Wt.	1.507	2.260	3.014	3.767	4.520	5.274	6.027	6.780	7.533	9.040	10.55	12.05
	Area	1.281	1.922	2.563	3.203	3.844	4.484	5.125	5.766	6.406	7.688	8.969	10.25
	$I_{x\text{-}x}$	11.22	16.83	22.44	28.04	33.65	39.26	44.87	50.48	56.09	67.31	78.52	89.74
	$I_{y\text{-}y}$	0.002	0.006	0.013	0.026	0.045	0.072	0.107	0.152	0.209	0.360	0.572	0.854
10 3/8	Wt.	1.525	2.287	3.051	3.813	4.576	5.338	6.101	6.863	7.625	9.150	10.68	12.21
	Area	1.297	1.945	2.594	3.242	3.891	4.539	5.188	5.836	6.484	7.781	9.078	10.38
	$I_{x\text{-}x}$	11.63	17.45	23.27	29.08	34.90	40.72	46.53	52.35	58.17	69.80	81.43	93.06
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.026	0.046	0.072	0.108	0.154	0.211	0.365	0.579	0.865
10 1/2	Wt.	1.543	2.315	3.087	3.859	4.630	5.402	6.174	6.946	7.718	9.261	10.81	12.35
	Area	1.313	1.969	2.625	3.281	3.938	4.594	5.250	5.906	6.563	7.875	9.188	10.50
	$I_{x\text{-}x}$	12.06	18.09	24.12	30.15	36.18	42.21	48.23	54.26	60.29	72.35	84.41	96.47
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.027	0.046	0.073	0.109	0.156	0.214	0.369	0.586	0.875
10 5/8	Wt.	1.562	2.343	3.123	3.904	4.685	5.466	6.248	7.029	7.810	9.372	10.93	12.50
	Area	1.328	1.992	2.656	3.320	3.984	4.648	5.313	5.977	6.641	7.969	9.297	10.63
	$I_{x\text{-}x}$	12.49	18.74	24.99	31.24	37.48	43.73	49.98	56.22	62.47	74.97	87.46	99.95
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.027	0.047	0.074	0.111	0.158	0.216	0.374	0.593	0.885
10 3/4	Wt.	1.580	2.370	3.160	3.951	4.741	5.531	6.321	7.111	7.901	9.482	11.06	12.64
	Area	1.344	2.016	2.688	3.359	4.031	4.703	5.375	6.047	6.719	8.063	9.406	10.75
	$I_{x\text{-}x}$	12.94	19.41	25.88	32.35	38.82	45.29	51.76	58.23	64.70	77.64	90.58	103.5
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.027	0.047	0.075	0.112	0.159	0.219	0.378	0.600	0.896
10 7/8	Wt.	1.598	2.398	3.198	3.996	4.796	5.595	6.395	7.194	7.993	9.591	11.19	12.79
	Area	1.359	2.039	2.719	3.398	4.078	4.758	5.438	6.117	6.797	8.156	9.516	10.88
	$I_{x\text{-}x}$	13.40	20.10	26.79	33.49	40.19	46.89	53.59	60.29	66.99	80.38	93.78	107.2
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.028	0.048	0.076	0.113	0.161	0.221	0.382	0.607	0.906

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

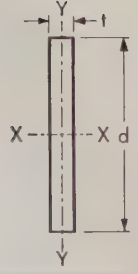
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
11	Wt.	1.617	2.426	3.234	4.042	4.851	5.660	6.468	7.276	8.085	9.702	11.32	12.94
	Area	1.375	2.063	2.750	3.438	4.125	4.813	5.500	6.188	6.875	8.250	9.625	11.00
	$I_{x\text{-}x}$	13.86	20.80	27.73	34.66	41.59	48.53	55.46	62.39	69.32	83.19	97.05	110.9
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.028	0.048	0.077	0.115	0.163	0.224	0.387	0.614	0.917
11 1/8	Wt.	1.639	2.453	3.270	4.089	4.906	5.724	6.542	7.359	8.177	9.813	11.45	13.09
	Area	1.391	2.086	2.781	3.477	4.172	4.867	5.563	6.258	6.953	8.344	9.734	11.13
	$I_{x\text{-}x}$	14.34	21.51	28.69	35.86	43.03	50.20	57.37	64.54	71.71	86.06	100.4	114.7
	$I_{y\text{-}y}$	0.002	0.006	0.014	0.028	0.049	0.078	0.116	0.165	0.226	0.391	0.621	0.927
11 1/4	Wt.	1.654	2.481	3.308	4.134	4.961	5.788	6.615	7.442	8.269	9.922	11.58	13.23
	Area	1.406	2.109	2.813	3.516	4.219	4.922	5.625	6.328	7.031	8.438	9.844	11.25
	$I_{x\text{-}x}$	14.83	22.25	29.66	37.08	44.49	51.91	59.33	66.74	74.16	88.99	103.8	118.7
	$I_{y\text{-}y}$	0.002	0.006	0.015	0.029	0.049	0.079	0.117	0.167	0.229	0.396	0.628	0.937
11 3/8	Wt.	1.672	2.508	3.345	4.181	5.017	5.853	6.689	7.524	8.360	10.03	11.70	13.38
	Area	1.422	2.133	2.844	3.555	4.266	4.977	5.688	6.398	7.109	8.531	9.953	11.38
	$I_{x\text{-}x}$	15.33	23.00	30.66	38.33	45.99	53.66	61.33	68.99	76.66	91.99	107.3	122.7
	$I_{y\text{-}y}$	0.002	0.006	0.015	0.029	0.050	0.079	0.118	0.169	0.231	0.400	0.635	0.948
11 1/2	Wt.	1.690	2.536	3.381	4.226	5.072	5.917	6.762	7.607	8.452	10.14	11.83	13.52
	Area	1.438	2.156	2.875	3.594	4.313	5.031	5.750	6.469	7.188	8.625	10.06	11.50
	$I_{x\text{-}x}$	15.84	23.76	31.69	39.61	47.53	55.45	63.37	71.29	79.21	95.06	110.9	126.7
	$I_{y\text{-}y}$	0.002	0.006	0.015	0.029	0.051	0.080	0.120	0.171	0.234	0.404	0.642	0.958
11 5/8	Wt.	1.709	2.564	3.417	4.272	5.126	5.981	6.836	7.690	8.545	10.25	11.96	13.68
	Area	1.453	2.180	2.906	3.633	4.359	5.086	5.813	6.539	7.266	8.719	10.17	11.63
	$I_{x\text{-}x}$	16.36	24.55	32.73	40.91	49.09	57.28	65.46	73.64	81.82	98.19	114.6	130.9
	$I_{y\text{-}y}$	0.002	0.006	0.015	0.030	0.051	0.081	0.121	0.172	0.237	0.409	0.649	0.969
11 3/4	Wt.	1.727	2.591	3.454	4.318	5.182	6.045	6.909	7.773	8.636	10.36	12.09	13.82
	Area	1.469	2.203	2.938	3.672	4.406	5.141	5.875	6.609	7.344	8.813	10.28	11.75
	$I_{x\text{-}x}$	16.90	25.35	33.80	42.25	50.69	59.14	67.59	76.04	84.49	101.4	118.3	135.2
	$I_{y\text{-}y}$	0.002	0.006	0.015	0.030	0.052	0.082	0.122	0.174	0.239	0.413	0.656	0.979
11 7/8	Wt.	1.745	2.619	3.491	4.364	5.237	6.109	6.983	7.856	8.728	10.47	12.22	13.97
	Area	1.484	2.227	2.969	3.711	4.453	5.195	5.938	6.680	7.422	8.906	10.39	11.88
	$I_{x\text{-}x}$	17.44	26.17	34.89	43.61	52.33	61.05	69.77	78.49	87.22	104.7	122.1	139.5
	$I_{y\text{-}y}$	0.002	0.007	0.015	0.030	0.052	0.083	0.124	0.176	0.242	0.417	0.663	0.990

TABLE 54

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2}; \quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

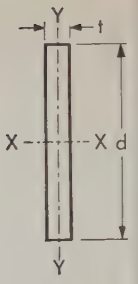
$$r_{x\text{-}x}=0.289\ d; \quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
12	Wt.	1.764	2.646	3.528	4.410	5.292	6.174	7.056	7.938	8.820	10.58	12.35	14.11
	Area	1.500	2.250	3.000	3.750	4 500	5.250	6.000	6.750	7.500	9.000	10.50	12.00
	$I_{x\text{-}x}$	18.00	27.00	36.00	45.00	54 00	63.00	72.00	81.00	90.00	108.0	126.0	144.0
	$I_{y\text{-}y}$	0.002	0.007	0.016	0.031	0 053	0.084	0.125	0.178	0.244	0.422	0.670	1.000
12¼	Wt.	1.800	2 701	3.602	4 502	5.403	6 302	7 203	8.104	9 003	10.81	12.61	14 41
	Area	1.531	2.297	3.063	3.828	4.594	5.359	6.125	6.891	7.656	9.188	10.72	12.25
	$I_{x\text{-}x}$	19 15	28 72	38.30	47 87	57.45	67 02	76 59	86.17	95.74	114.9	134.0	153.2
	$I_{y\text{-}y}$	0.002	0.007	0.016	0.031	0.054	0.085	0.128	0.182	0.249	0.431	0.684	1.021
12½	Wt.	1.838	2.756	3.675	4.594	5.512	6.431	7.350	8.269	9.188	11.02	12.87	14.70
	Area	1.563	2.344	3.125	3.906	4.688	5 469	6 250	7.031	7.813	9.375	10.94	12.50
	$I_{x\text{-}x}$	20.35	30.52	40.69	50.86	61.04	71.21	81.38	91.55	101.7	122.1	142.4	162.8
	$I_{y\text{-}y}$	0.002	0.007	0.016	0.032	0.055	0.087	0.130	0.185	0.254	0.439	0.698	1.042
12¾	Wt.	1.875	2.812	3.749	4.685	5.622	6.560	7.497	8.434	9.372	11.25	13.12	14.99
	Area	1.594	2.391	3.188	3.984	4.781	5.578	6.375	7.172	7.969	9 563	11.16	12.75
	$I_{x\text{-}x}$	21 59	32.39	43.18	53 98	64.77	75 57	86.36	97.16	108.0	129.5	151.1	172.7
	$I_{y\text{-}y}$	0.002	0.007	0.017	0.032	0.056	0.089	0.133	0.189	0.259	0.448	0.712	1.062
13	Wt.	1.911	2.866	3 822	4.778	5 733	6.688	7.644	8.600	9.555	11.47	13.38	15.29
	Area	1.625	2.438	3.250	4.063	4.875	5.688	6.500	7.313	8.125	9.750	11.38	13.00
	$I_{x\text{-}x}$	22.89	34.33	45.77	57.21	68.66	80 10	91.54	103.0	114.4	137.3	160.2	183.1
	$I_{y\text{-}y}$	0.002	0.007	0.017	0.033	0.057	0.091	0 135	0.193	0.264	0.457	0.726	1.083
13¼	Wt.	1.947	2.921	3.896	4 870	5.844	6.817	7 791	8.765	9.738	11.69	13.63	15.58
	Area	1.656	2.484	3.313	4 141	4.969	5.797	6 625	7.453	8.281	9.938	11.59	13.25
	$I_{x\text{-}x}$	24.23	36.35	48.46	60 58	72.69	84.81	96 93	109.0	121.2	145.4	169.6	193.9
	$I_{y\text{-}y}$	0.002	0.007	0.017	0 034	0.058	0.092	0 138	0.197	0.270	0.466	0.740	1.104
13½	Wt.	1.984	2.977	3.969	4.961	5.953	6.946	7.938	8.930	9.922	11 91	13.89	15.88
	Area	1.688	2.531	3.375	4.219	5.063	5.906	6.750	7.594	8.438	10.13	11.81	13.50
	$I_{x\text{-}x}$	25.63	38.44	51.26	64.07	76.89	89.70	102.5	115.3	128.1	153.8	179.4	205.0
	$I_{y\text{-}y}$	0.002	0.007	0.018	0.034	0.059	0.094	0.141	0.200	0 275	0.475	0.754	1.125
13¾	Wt.	2.022	3.042	4.043	5.053	6.063	7.075	8.085	9.095	10.11	12.12	14.15	16.17
	Area	1.719	2.578	3.438	4.297	5.156	6.016	6.875	7.734	8.594	10.31	12.03	13.75
	$I_{x\text{-}x}$	27 08	40.62	54.16	67.70	81.24	94.78	108.3	121.9	135.4	162.5	189.6	216.6
	$I_{y\text{-}y}$	0.002	0.008	0.018	0.035	0.060	0.096	0.143	0.204	0.280	0.483	0.768	1.146

TABLE 54

rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

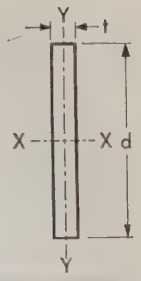
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
14	Wt.	2.085	3.087	4.116	5.145	6.174	7.203	8.232	9.261	10.29	12.35	14.41	16.46
	Area	1.750	2.625	3.500	4.375	5.250	6.125	7.000	7.875	8.750	10.50	12.25	14.00
	$I_{x\text{-}x}$	28.58	42.88	57.17	71.46	85.75	100.0	114.3	128.6	142.9	171.5	200.1	228.7
	$I_{y\text{-}y}$	0.002	0.008	0.018	0.036	0.062	0.098	0.146	0.208	0.285	0.492	0.782	1.167
14 1/4	Wt.	2.094	3.142	4.190	5.237	6.285	7.331	8.379	9.427	10.47	12.57	14.66	16.76
	Area	1.781	2.672	3.563	4.453	5.344	6.234	7.125	8.016	8.906	10.69	12.47	14.25
	$I_{x\text{-}x}$	30.14	45.21	60.28	75.36	90.43	105.5	120.6	135.6	150.7	180.9	211.0	241.1
	$I_{y\text{-}y}$	0.002	0.008	0.019	0.036	0.063	0.099	0.148	0.211	0.290	0.501	0.796	1.187
14 1/2	Wt.	2.132	3.197	4.263	5.329	6.394	7.460	8.526	9.592	10.66	12.79	14.92	17.05
	Area	1.813	2.719	3.625	4.531	5.438	6.344	7.250	8.156	9.063	10.88	12.69	14.50
	$I_{x\text{-}x}$	31.76	47.63	63.51	79.39	95.27	111.1	127.0	142.9	158.8	190.5	222.3	254.1
	$I_{y\text{-}y}$	0.002	0.008	0.019	0.037	0.064	0.101	0.151	0.215	0.295	0.510	0.809	1.208
14 3/4	Wt.	2.169	3.253	4.337	5.420	6.504	6.589	8.673	9.757	10.84	13.01	15.18	17.35
	Area	1.844	2.766	3.688	4.609	5.531	6.453	7.375	8.297	9.219	11.06	12.91	14.75
	$I_{x\text{-}x}$	33.43	50.14	66.86	83.57	100.3	117.0	133.7	150.4	167.1	200.6	234.0	267.4
	$I_{y\text{-}y}$	0.002	0.008	0.019	0.038	0.065	0.103	0.154	0.219	0.300	0.519	0.823	1.229
15	Wt.	2.205	3.308	4.411	5.512	6.615	7.718	8.820	9.922	11.02	13.23	15.44	17.64
	Area	1.875	2.813	3.750	4.688	5.625	6.563	7.500	8.438	9.375	11.25	13.13	15.00
	$I_{x\text{-}x}$	35.16	52.73	70.31	87.89	105.5	123.0	140.6	158.2	175.8	210.9	246.1	281.3
	$I_{y\text{-}y}$	0.002	0.008	0.020	0.038	0.066	0.105	0.156	0.222	0.305	0.527	0.837	1.250
15 1/4	Wt.	2.241	3.362	4.484	5.605	6.726	7.846	8.967	10.09	11.21	13.45	15.69	17.93
	Area	1.906	2.859	3.813	4.766	5.719	6.672	7.625	8.578	9.531	11.44	13.34	15.25
	$I_{x\text{-}x}$	36.94	55.42	73.89	92.36	110.8	129.3	147.8	166.2	184.7	221.7	258.6	295.5
	$I_{y\text{-}y}$	0.002	0.008	0.020	0.039	0.067	0.106	0.159	0.226	0.310	0.536	0.851	1.271
15 1/2	Wt.	2.278	3.418	4.557	5.696	6.836	7.975	9.114	10.25	11.39	13.67	15.95	18.23
	Area	1.938	2.906	3.875	4.844	5.813	6.781	7.750	8.719	9.688	11.63	13.56	15.50
	$I_{x\text{-}x}$	38.79	58.19	77.58	96.98	116.4	135.8	155.2	174.6	194.0	232.7	271.5	310.3
	$I_{y\text{-}y}$	0.003	0.009	0.020	0.039	0.068	0.108	0.161	0.230	0.315	0.545	0.865	1.292
15 3/4	Wt.	2.316	3.473	4.631	5.788	6.945	8.104	9.261	10.42	11.58	13.89	16.21	18.52
	Area	1.969	2.953	3.938	4.922	5.906	6.891	7.875	8.859	9.844	11.81	13.78	15.75
	$I_{x\text{-}x}$	40.70	61.05	81.40	101.7	122.1	142.4	162.8	183.1	203.5	244.2	284.9	325.6
	$I_{y\text{-}y}$	0.003	0.009	0.021	0.040	0.069	0.110	0.164	0.234	0.320	0.554	0.879	1.312

TABLE 54

RECTANGLES — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

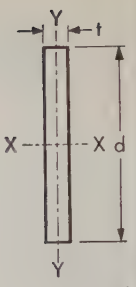
$$r_{x\text{-}x}=0.289\,d;\quad r_{y\text{-}y}=0.289\,t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
16	Wt.	2.352	3.528	4.704	5.880	7.056	8.232	9.408	10.58	11.76	14.11	16.46	18.82
	Area	2.000	3.000	4.000	5.000	6.000	7.000	8 000	9.000	10.00	12.00	14.00	16.00
	$I_{x\text{-}x}$	42.67	64.00	85.33	106.7	128.0	149.3	170.7	192.0	213.3	256.0	298.7	341.3
	$I_{y\text{-}y}$	0.003	0.009	0.021	0.041	0.070	0.112	0.167	0.237	0.326	0.562	0.893	1.333
16 1/4	Wt.	2.388	3 583	4.778	5.972	7.167	8.360	9.555	10.75	11.95	14.34	16.72	19.11
	Area	2.031	3 047	4 063	5 078	6 094	7.109	8.125	9 141	10 16	12.19	14.22	16.25
	$I_{x\text{-}x}$	44.70	67.05	89.40	111 7	134.1	156.4	178 8	201.1	223.5	268.2	312.9	357.6
	$I_{y\text{-}y}$	0.003	0 009	0.021	0 041	0.071	0.113	0.169	0.241	0.331	0.571	0.907	1.354
16 1/2	Wt.	2.426	3.638	4 851	6.064	7.276	8.489	9.702	10.71	12.13	14.55	16.98	19.40
	Area	2.063	3.094	4.125	5.156	6 188	7.219	8.250	9.281	10.31	12.38	14.44	16.50
	$I_{x\text{-}x}$	46.79	70.19	93.59	117.0	140.4	163.8	187.2	210.6	234.0	280.8	327.6	374.3
	$I_{y\text{-}y}$	0.003	0.009	0.021	0.042	0.073	0.115	0.172	0.245	0.336	0.580	0.921	1.375
16 3/4	Wt.	2.463	3.694	4.925	6.155	7.386	8.618	9.849	11.08	12.31	14.77	17.24	19.70
	Area	2.094	3.141	4.188	5.234	6.281	7.328	8.375	9.422	10.47	12.56	14.66	16.75
	$I_{x\text{-}x}$	48.95	73.43	97.90	122.4	146.9	171.3	195.8	220.3	244.8	293.7	342.7	391.6
	$I_{y\text{-}y}$	0.003	0.009	0.022	0.043	0.074	0.117	0.174	0.248	0.341	0.589	0.935	1.396
17	Wt.	2.499	3.748	4 998	6.248	7.497	8.746	9.996	11.24	12.50	14.99	17.50	19.99
	Area	2.125	3.188	4.250	5.313	6.375	7.438	8.500	9.563	10.63	12.75	14.88	17.00
	$I_{x\text{-}x}$	51.18	76.77	102.4	127.9	153.5	179.1	204.7	230.3	255.9	307.1	358.2	409.4
	$I_{y\text{-}y}$	0.003	0.009	0.022	0.043	0.075	0.119	0.177	0.252	0.346	0.598	0.949	1.417
17 1/4	Wt.	2.535	3.803	5.072	6.340	7.608	8.769	10.14	11.41	12.68	15.22	17.75	20.29
	Area	2.156	3.234	4.313	5.391	6.469	7.547	8.625	9.703	10.78	12.94	15.09	17.25
	$I_{x\text{-}x}$	53.47	80.20	106.9	133.7	160.4	187.1	213.9	240.6	267.3	320.8	374.3	427.7
	$I_{y\text{-}y}$	0.003	0.009	0.022	0.044	0.076	0.120	0.180	0.256	0.351	0.606	0.963	1.437
17 1/2	Wt.	2.572	3.859	5.145	6.431	7.718	9.004	10.29	11.58	12.86	15.44	18.00	20.58
	Area	2.188	3.281	4.375	5.469	6.563	7.656	8.750	9.844	10.94	13.13	15.31	17.50
	$I_{x\text{-}x}$	55.83	83.74	111.7	139.6	167.5	195.4	223.3	251.2	279.1	335.0	390.8	446.6
	$I_{y\text{-}y}$	0.003	0.010	0.023	0.045	0.077	0.122	0.182	0.260	0.356	0.615	0.977	1.458
17 3/4	Wt.	2 610	3.914	5.219	6.523	7.827	9.133	10.44	11.74	13.04	15.65	18.26	20.87
	Area	2.219	3.328	4.438	5.547	6.656	7.766	8.875	9.984	11.09	13.31	15.53	17.75
	$I_{x\text{-}x}$	58.25	87.38	116.5	145.6	174.8	203.9	233.0	262.1	291.3	349.5	407.8	466.0
	$I_{y\text{-}y}$	0.003	0.010	0.023	0.045	0.078	0.124	0.185	0.263	0.361	0.624	0.991	1.479

TABLE
54

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

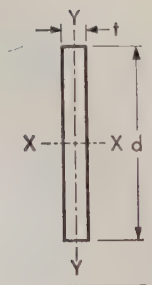
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
18	Wt.	2.646	3.969	5.292	6.615	7.938	9.261	10.58	11.91	13.23	15.88	18.52	21.17
	Area	2.250	3.375	4.500	5.625	6.750	7.875	9.000	10.13	11.25	13.50	15.75	18.00
	$I_{x\text{-}x}$	60.75	91.13	121.5	151.9	182.3	212.6	243.0	273.4	303.8	364.5	425.3	486.0
	$I_{y\text{-}y}$	0.003	0.010	0.023	0.046	0.079	0.126	0.188	0.267	0.366	0.633	1.005	1.500
18 1/4	Wt.	2.682	4.024	5.366	6.707	8.049	9.389	10.73	12.08	13.42	16.10	18.78	21.46
	Area	2.281	3.422	4.563	5.703	6.844	7.984	9.125	10.27	11.41	13.69	15.97	18.25
	$I_{x\text{-}x}$	63.32	94.97	126.6	158.3	189.9	221.6	253.3	284.9	316.6	379.9	443.2	506.5
	$I_{y\text{-}y}$	0.003	0.010	0.024	0.046	0.080	0.127	0.190	0.271	0.371	0.642	1.019	1.521
18 1/2	Wt.	2.720	4.079	5.439	6.799	8.158	9.518	10.88	12.24	13.60	16.32	19.04	21.76
	Area	2.313	3.469	4.625	5.781	6.938	8.094	9.250	10.41	11.56	13.88	16.19	18.50
	$I_{x\text{-}x}$	65.95	98.93	131.9	164.9	197.9	230.8	263.8	296.8	329.8	395.7	461.7	527.6
	$I_{y\text{-}y}$	0.003	0.010	0.024	0.047	0.081	0.129	0.193	0.274	0.376	0.650	1.033	1.542
18 3/4	Wt.	2.757	4.135	5.513	6.890	8.268	9.647	11.03	12.41	13.78	16.53	19.30	22.05
	Area	2.344	3.516	4.688	5.859	7.031	8.203	9.375	10.55	11.72	14.06	16.41	18.75
	$I_{x\text{-}x}$	68.66	103.0	137.3	171.7	206.0	240.3	274.7	309.0	343.3	412.0	480.7	549.3
	$I_{y\text{-}y}$	0.003	0.010	0.024	0.048	0.082	0.131	0.195	0.278	0.381	0.659	1.047	1.562
19	Wt.	2.793	4.190	5.586	6.982	8.379	9.776	11.17	12.57	13.96	16.76	19.56	22.34
	Area	2.375	3.563	4.750	5.938	7.125	8.313	9.500	10.69	11.88	14.25	16.63	19.00
	$I_{x\text{-}x}$	71.45	107.2	142.9	178.6	214.3	250.1	285.8	321.5	357.2	428.7	500.1	571.6
	$I_{y\text{-}y}$	0.003	0.010	0.025	0.048	0.083	0.133	0.198	0.282	0.387	0.668	1.061	1.583
19 1/4	Wt.	2.829	4.244	5.660	7.075	8.490	9.904	11.32	12.74	14.15	16.98	19.80	22.64
	Area	2.406	3.609	4.813	6.016	7.219	8.422	9.625	10.83	12.03	14.44	16.84	19.25
	$I_{x\text{-}x}$	74.31	111.5	148.6	185.8	222.9	260.1	297.2	334.4	371.5	445.8	520.1	594.4
	$I_{y\text{-}y}$	0.003	0.011	0.025	0.049	0.085	0.134	0.201	0.286	0.392	0.677	1.075	1.604
19 1/2	Wt.	2.866	4.300	5.733	7.166	8.600	10.03	11.47	12.90	14.33	17.20	20.06	22.93
	Area	2.438	3.656	4.875	6.094	7.313	8.531	9.750	10.97	12.19	14.63	17.06	19.50
	$I_{x\text{-}x}$	77.24	115.9	154.5	193.1	231.7	270.3	309.0	347.6	386.2	463.4	540.7	617.9
	$I_{y\text{-}y}$	0.003	0.011	0.025	0.050	0.086	0.136	0.203	0.289	0.397	0.686	1.089	1.625
19 3/4	Wt.	2.904	4.355	5.807	7.258	8.709	10.16	11.61	13.07	14.51	17.42	20.32	23.23
	Area	2.469	3.703	4.938	6.172	7.406	8.641	9.875	11.11	12.34	14.81	17.28	19.75
	$I_{x\text{-}x}$	80.25	120.4	160.5	200.6	240.7	280.9	321.0	361.1	401.2	481.5	561.7	642.0
	$I_{y\text{-}y}$	0.003	0.011	0.026	0.050	0.087	0.138	0.206	0.293	0.402	0.694	1.103	1.646

TABLE 54

rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2}; \quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

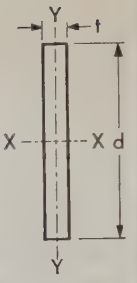
$$r_{x\text{-}x}=0.289\ d; \quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
20	Wt.	2.940	4.411	5.880	7.350	8.820	10.29	11.76	13.23	14.70	17.64	20.58	23.52
	Area	2.500	3.750	5.000	6.250	7.500	8.750	10.00	11.25	12.50	15.00	17.50	20.00
	$I_{x\text{-}x}$	83.33	125.0	166.7	208.3	250.0	291.7	333.3	375.0	416.7	500.0	583.3	666.7
	$I_{y\text{-}y}$	0.003	0.011	0.026	0.051	0.088	0.140	0.208	0.297	0.407	0.703	1.117	1.667
20 1/4	Wt.	2.976	4.465	5.954	7.442	8.931	10.42	11.91	13.39	14.89	17.86	20.84	23.81
	Area	2.531	3.797	5.063	6.328	7.594	8.859	10.13	11.39	12.66	15.19	17.72	20.25
	$I_{x\text{-}x}$	86.50	129.7	173.0	216.2	259.5	302.7	346.0	389.2	432.5	519.0	605.5	692.0
	$I_{y\text{-}y}$	0.003	0.011	0.026	0.051	0.089	0.141	0.211	0.300	0.412	0.712	1.130	1.687
20 1/2	Wt.	3.014	4.520	6.027	7.534	9.040	10.55	12.05	13.56	15.07	18.08	21.10	24.11
	Area	2.563	3.844	5.125	6.406	7.688	8.969	10.25	11.53	12.81	15.38	17.94	20.50
	$I_{x\text{-}x}$	89.74	134.6	179.5	224.4	269.2	314.1	359.0	403.8	448.7	538.4	628.2	717.9
	$I_{y\text{-}y}$	0.003	0.011	0.027	0.052	0.090	0.143	0.214	0.304	0.417	0.721	1.144	1.708
20 3/4	Wt.	3.051	4.576	6.101	7.625	9.150	10.68	12.21	13.72	15.25	18.30	21.36	24.40
	Area	2.594	3.891	5.188	6.484	7.781	9.078	10.38	11.67	12.97	15.56	18.16	20.75
	$I_{x\text{-}x}$	93.06	139.6	186.1	232.7	279.2	325.7	372.3	418.8	465.3	558.4	651.5	744.5
	$I_{y\text{-}y}$	0.003	0.011	0.027	0.053	0.091	0.145	0.216	0.308	0.422	0.729	1.158	1.729
21	Wt.	3.087	4.630	6.174	7.718	9.261	10.80	12.35	13.89	15.44	18.52	21.61	24.70
	Area	2.625	3.938	5.250	6.563	7.875	9.188	10.50	11.81	13.13	15.75	18.38	21.00
	$I_{x\text{-}x}$	96.47	144.7	192.9	241.2	289.4	337.6	385.9	434.1	482.3	578.8	675.3	771.8
	$I_{y\text{-}y}$	0.003	0.012	0.027	0.053	0.092	0.147	0.219	0.311	0.427	0.738	1.172	1.750
21 1/4	Wt.	3.123	4.685	6.248	7.810	9.372	10.93	12.50	14.05	15.62	18.75	21.86	24.99
	Area	2.656	3.984	5.313	6.641	7.969	9.297	10.63	11.95	13.28	15.94	18.59	21.25
	$I_{x\text{-}x}$	99.96	149.9	199.9	249.9	299.9	349.8	399.8	449.8	499.8	599.7	699.7	799.6
	$I_{y\text{-}y}$	0.003	0.012	0.028	0.054	0.093	0.148	0.221	0.315	0.432	0.747	1.186	1.771
21 1/2	Wt.	3.160	4.741	6.321	7.901	9.482	11.06	12.64	14.22	15.80	18.96	22.12	25.28
	Area	2.688	4.031	5.375	6.719	8.063	9.406	10.75	12.09	13.44	16.13	18.81	21.50
	$I_{x\text{-}x}$	103.5	155.3	207.1	258.8	310.6	362.3	414.1	465.9	517.6	621.1	724.7	828.2
	$I_{y\text{-}y}$	0.003	0.012	0.028	0.055	0.094	0.150	0.224	0.319	0.437	0.756	1.200	1.792
21 3/4	Wt.	3.198	4.796	6.395	7.993	9.591	11.19	12.79	14.38	15.98	19.18	22.38	25.58
	Area	2.719	4.078	5.438	6.797	8.156	9.516	10.88	12.23	13.59	16.31	19.03	21.75
	$I_{x\text{-}x}$	107.2	160.8	214.4	267.9	321.5	375.1	428.7	482.3	535.9	643.1	750.2	857.4
	$I_{y\text{-}y}$	0.004	0.012	0.028	0.055	0.096	0.152	0.227	0.323	0.443	0.765	1.214	1.812

TABLE 54

Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2}, \quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

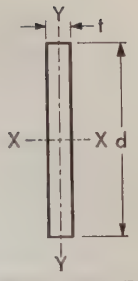
$$r_{x\text{-}x}=0.289\ d; \quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
22	Wt.	3.234	4.851	6.468	8.085	9.702	11.32	12.94	14.55	16.17	19.40	22.64	25.87
	Area	2.750	4.125	5.500	6.875	8.250	9.625	11.00	12.38	13.75	16.50	19.25	22.00
	$I_{x\text{-}x}$	110.9	166.4	221.8	277.3	332.8	388.2	443.7	499.1	554.6	665.5	776.4	887.3
	$I_{y\text{-}y}$	0.004	0.012	0.029	0.056	0.097	0.154	0.229	0.326	0.448	0.773	1.228	1.833
22 1/4	Wt.	3.270	4.906	6.542	8.177	9.813	11.45	13.09	14.72	16.36	19.63	22.90	26.17
	Area	2.781	4.172	5.563	6.953	8.344	9.734	11.13	12.52	13.91	16.69	19.47	22.25
	$I_{x\text{-}x}$	114.7	172.1	229.5	286.8	344.2	401.6	459.0	516.3	573.7	688.4	803.2	917.9
	$I_{y\text{-}y}$	0.004	0.012	0.029	0.057	0.098	0.155	0.232	0.330	0.453	0.782	1.242	1.854
22 1/2	Wt.	3.308	4.961	6.615	8.269	9.922	11.58	13.23	14.88	16.54	19.84	23.16	26.46
	Area	2.813	4.219	5.625	7.031	8.438	9.844	11.25	12.66	14.06	16.88	19.69	22.50
	$I_{x\text{-}x}$	118.7	178.0	237.3	296.6	356.0	415.3	474.6	534.0	593.3	711.9	830.6	949.3
	$I_{y\text{-}y}$	0.004	0.012	0.029	0.057	0.099	0.157	0.234	0.334	0.458	0.791	1.256	1.875
22 3/4	Wt.	3.345	5.017	6.689	8.360	10.03	11.70	13.38	15.05	16.72	20.06	23.41	26.75
	Area	2.844	4.266	5.688	7.109	8.531	9.953	11.38	12.80	14.22	17.06	19.91	22.75
	$I_{x\text{-}x}$	122.7	184.0	245.3	306.6	368.0	429.3	490.6	552.0	613.3	735.9	858.6	981.3
	$I_{y\text{-}y}$	0.004	0.012	0.030	0.058	0.100	0.159	0.237	0.337	0.463	0.800	1.270	1.896
23	Wt.	3.381	5.072	6.762	8.452	10.14	11.83	13.52	15.21	16.90	20.29	23.67	27.05
	Area	2.875	4.313	5.750	7.188	8.625	10.06	11.50	12.94	14.38	17.25	20.13	23.00
	$I_{x\text{-}x}$	126.7	190.1	253.5	316.8	380.2	443.6	507.0	570.3	633.7	760.4	887.2	1014.
	$I_{y\text{-}y}$	0.004	0.013	0.030	0.058	0.101	0.161	0.240	0.341	0.468	0.809	1.284	1.917
23 1/4	Wt.	3.417	5.126	6.836	8.545	10.25	11.96	13.68	15.38	17.09	20.51	23.92	27.34
	Area	2.906	4.359	5.813	7.266	8.719	10.17	11.63	13.08	14.53	17.44	20.34	23.25
	$I_{x\text{-}x}$	130.9	196.4	261.8	327.3	392.8	458.2	523.7	589.1	654.6	785.5	916.4	1047.
	$I_{y\text{-}y}$	0.004	0.013	0.030	0.059	0.102	0.162	0.242	0.345	0.473	0.817	1.298	1.937
23 1/2	Wt.	3.454	5.182	6.909	8.636	10.36	12.09	13.82	15.54	17.27	20.73	24.18	27.64
	Area	2.938	4.406	5.875	7.344	8.813	10.28	11.75	13.22	14.69	17.63	20.56	23.50
	$I_{x\text{-}x}$	135.2	202.8	270.4	338.0	405.6	473.2	540.8	608.3	675.9	811.1	946.3	1082.
	$I_{y\text{-}y}$	0.004	0.013	0.031	0.060	0.103	0.164	0.245	0.349	0.478	0.826	1.312	1.958
23 3/4	Wt.	3.492	5.237	6.983	8.728	10.47	12.22	13.97	15.71	17.45	20.94	24.44	27.93
	Area	2.969	4.453	5.938	7.422	8.906	10.39	11.88	13.36	14.84	17.81	20.78	23.75
	$I_{x\text{-}x}$	139.5	209.3	279.1	348.9	418.6	488.4	558.2	627.9	697.7	837.3	976.8	1116.
	$I_{y\text{-}y}$	0.004	0.013	0.031	0.060	0.104	0.166	0.247	0.352	0.483	0.835	1.326	1.979

TABLE 54

rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

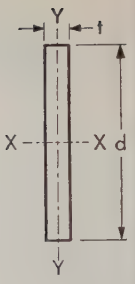
Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
24	Wt.	3.528	5.292	7.056	8.820	10.58	12.35	14.11	15.88	17.64	21.12	24.70	28.22
	Area	3.000	4.500	6.000	7.500	9.000	10.50	12.00	13.50	15.00	18.00	21.00	24.00
	$I_{x\text{-}x}$	144.0	216.0	288.0	360.0	432.0	504.0	576.0	648.0	720.0	864.0	1008.	1152.
	$I_{y\text{-}y}$	0.004	0.013	0.031	0.061	0.105	0.167	0.250	0.356	0.488	0.844	1.340	2.000
24½	Wt.	3.602	5.403	7.203	9.003	10.81	12.61	14.41	16.21	18.00	21.61	25.21	28.81
	Area	3.063	4.594	6.125	7.656	9.188	10.72	12.25	13.78	15.31	18.38	21.44	24.50
	$I_{x\text{-}x}$	153.2	229.8	306.4	383.0	459.6	536.2	612.8	689.3	765.9	919.1	1072.	1226.
	$I_{y\text{-}y}$	0.004	0.013	0.032	0.062	0.108	0.171	0.255	0.363	0.498	0.861	1.368	2.042
25	Wt.	3.675	5.512	7.350	9.188	11.02	12.86	14.70	16.54	18.38	22.05	25.73	29.40
	Area	3.125	4.688	6.250	7.813	9.375	10.94	12.50	14.06	15.63	18.75	21.88	25.00
	$I_{x\text{-}x}$	162.8	244.1	325.5	406.9	488.3	569.7	651.0	732.4	813.8	976.6	1139.	1302.
	$I_{y\text{-}y}$	0.004	0.014	0.033	0.064	0.110	0.174	0.260	0.371	0.509	0.879	1.396	2.083
25½	Wt.	3.749	5.622	7.497	9.372	11.25	13.12	14.99	16.86	18.75	22.50	26.24	29.99
	Area	3.188	4.781	6.375	7.969	9.563	11.16	12.75	14.34	15.94	19.13	22.31	25.50
	$I_{x\text{-}x}$	172.7	259.1	345.4	431.8	518.2	604.5	690.9	777.2	863.6	1036.	1209.	1382.
	$I_{y\text{-}y}$	0.004	0.014	0.033	0.065	0.112	0.178	0.266	0.378	0.519	0.896	1.424	2.125
26	Wt.	3.822	5.733	7.644	9.555	11.47	13.38	15.29	17.20	19.11	22.93	26.75	30.58
	Area	3.250	4.875	6.500	8.125	9.750	11.38	13.00	14.63	16.25	19.50	22.75	26.00
	$I_{x\text{-}x}$	183.1	274.6	366.2	457.7	549.3	640.8	732.3	823.9	915.4	1099.	1282.	1465.
	$I_{y\text{-}y}$	0.004	0.014	0.034	0.066	0.114	0.181	0.271	0.386	0.529	0.914	1.452	2.167
26½	Wt.	3.896	5.844	7.791	9.738	11.69	13.63	15.58	17.53	19.47	23.38	27.27	31.16
	Area	3.313	4.969	6.625	8.281	9.938	11.59	13.25	14.91	16.56	19.88	23.19	26.50
	$I_{x\text{-}x}$	193.9	290.8	387.7	484.6	581.6	678.5	775.4	872.3	969.3	1163.	1357.	1551.
	$I_{y\text{-}y}$	0.004	0.015	0.035	0.067	0.116	0.185	0.276	0.393	0.539	0.932	1.479	2.208
27	Wt.	3.969	5.954	7.938	9.922	11.91	13.89	15.88	17.86	19.84	23.81	27.79	31.75
	Area	3.375	5.063	6.750	8.438	10.13	11.81	13.50	15.19	16.88	20.25	23.63	27.00
	$I_{x\text{-}x}$	205.0	307.5	410.1	512.6	615.1	717.6	820.1	922.6	1025.	1230.	1435.	1640.
	$I_{y\text{-}y}$	0.004	0.015	0.035	0.069	0.119	0.188	0.281	0.400	0.549	0.949	1.507	2.250
27½	Wt.	4.043	6.063	8.085	10.11	12.12	14.15	16.17	18.19	20.22	24.26	28.29	32.34
	Area	3.438	5.156	6.875	8.594	10.31	12.03	13.75	15.47	17.19	20.63	24.06	27.50
	$I_{x\text{-}x}$	216.6	325.0	433.3	541.6	649.9	758.2	866.5	974.9	1083.	1300.	1516.	1733.
	$I_{y\text{-}y}$	0.004	0.015	0.036	0.070	0.121	0.192	0.286	0.408	0.559	0.967	1.535	2.292

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

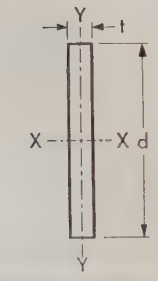
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
28	Wt.	4.116	6.174	8.232	10.29	12.35	14.41	16.46	18.52	20.58	24.70	28.81	32.93
	Area	3.500	5.250	7.000	8.750	10.50	12.25	14.00	15.75	17.50	21.00	24.50	28.00
	$I_{x\text{-}x}$	228.7	343.0	457.3	571.7	686.0	800.3	914.7	1029.	1143.	1372.	1601.	1829.
	$I_{y\text{-}y}$	0.005	0.015	0.036	0.071	0.123	0.195	0.292	0.415	0.570	0.984	1.563	2.333
28½	Wt.	4.190	6.285	8.379	10.47	12.57	14.66	16.76	18.85	20.94	25.14	29.33	33.52
	Area	3.563	5.344	7.125	8.906	10.69	12.47	14.25	16.03	17.81	21.38	24.94	28.50
	$I_{x\text{-}x}$	241.1	361.7	482.3	602.8	723.4	844.0	964.5	1085.	1206.	1447.	1688.	1929.
	$I_{y\text{-}y}$	0.005	0.016	0.037	0.072	0.125	0.199	0.297	0.423	0.580	1.002	1.591	2.375
29	Wt.	4.236	6.394	8.526	10.66	12.79	14.21	17.05	19.18	21.32	25.58	29.85	34.10
	Area	3.625	5.438	7.250	9.063	10.88	12.69	14.50	16.31	18.13	21.75	25.38	29.00
	$I_{x\text{-}x}$	254.1	381.1	508.1	635.1	762.2	889.2	1016.	1143.	1270.	1524.	1778.	2032.
	$I_{y\text{-}y}$	0.005	0.016	0.038	0.074	0.127	0.202	0.302	0.430	0.590	1.020	1.619	2.417
29½	Wt.	4.337	6.504	8.673	10.74	13.01	15.18	17.35	19.51	21.69	26.02	30.35	34.69
	Area	3.688	5.531	7.375	9.219	11.06	12.91	14.75	16.59	18.44	22.13	25.81	29.50
	$I_{x\text{-}x}$	267.4	401.1	534.8	668.5	802.3	936.0	1070.	1203.	1337.	1605.	1872.	2139.
	$I_{y\text{-}y}$	0.005	0.016	0.038	0.075	0.130	0.206	0.307	0.438	0.600	1.037	1.647	2.458
30	Wt.	4.411	6.615	8.820	11.02	13.23	15.44	17.64	19.84	22.05	26.46	30.87	35.28
	Area	3.750	5.625	7.500	9.375	11.25	13.13	15.00	16.88	18.75	22.50	26.25	30.00
	$I_{x\text{-}x}$	281.3	421.9	562.5	703.1	843.8	984.4	1125.	1266.	1406.	1688.	1969.	2250.
	$I_{y\text{-}y}$	0.005	0.016	0.039	0.076	0.132	0.209	0.313	0.445	0.610	1.055	1.675	2.500
30½	Wt.	4.484	6.726	8.967	11.21	13.45	15.69	17.93	20.18	22.41	26.91	31.39	35.87
	Area	3.813	5.719	7.625	9.531	11.44	13.34	15.25	17.16	19.06	22.88	26.69	30.50
	$I_{x\text{-}x}$	295.6	443.3	591.1	738.9	886.7	1034.	1182.	1330.	1478.	1773.	2069.	2364.
	$I_{y\text{-}y}$	0.005	0.017	0.040	0.078	0.134	0.213	0.318	0.452	0.621	1.072	1.703	2.542
31	Wt.	4.557	6.836	9.114	11.39	13.67	15.95	18.23	20.51	22.78	27.34	31.90	36.46
	Area	3.875	5.813	7.750	9.688	11.63	13.56	15.50	17.44	19.38	23.25	27.13	31.00
	$I_{x\text{-}x}$	310.3	465.5	620.6	775.8	931.0	1086.	1241.	1396.	1552.	1862.	2172.	2483.
	$I_{y\text{-}y}$	0.005	0.017	0.040	0.079	0.136	0.216	0.323	0.460	0.631	1.090	1.731	2.583
31½	Wt.	4.631	6.945	9.261	11.58	13.89	16.21	18.52	20.84	23.16	27.79	32.41	37.04
	Area	3.938	5.906	7.875	9.844	11.81	13.78	15.75	17.72	19.69	23.63	27.56	31.50
	$I_{x\text{-}x}$	325.6	488.4	651.2	814.0	976.8	1140.	1302.	1465.	1628.	1954.	2279.	2605.
	$I_{y\text{-}y}$	0.005	0.017	0.041	0.080	0.138	0.220	0.328	0.467	0.641	1.107	1.759	2.625

TABLE 54

Rectangles — Elements of Sections

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\,d;\quad r_{y\text{-}y}=0.289\,t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
32	Wt.	4.704	7.056	9.408	11.76	14.11	16.46	18.82	21.17	23.52	28.22	32.93	37.63
	Area	4.000	6.000	8.000	10.00	12.00	14.00	16.00	18.00	20.00	24.00	28.00	32.00
	$I_{x\text{-}x}$	341.3	512.0	682.7	853.3	1024.	1195.	1365.	1536.	1707.	2048.	2389.	2731.
	$I_{y\text{-}y}$	0.005	0.018	0.042	0.081	0.141	0.223	0.333	0.475	0.651	1.125	1.786	2.667
32½	Wt.	4.778	7.167	9.555	11.95	14.34	16.72	19.11	21.50	23.88	28.67	33.45	38.22
	Area	4.063	6.094	8.125	10.16	12.19	14.22	16.25	18.28	20.31	24.38	28.44	32.50
	$I_{x\text{-}x}$	357.6	536.4	715.2	894.0	1073.	1252.	1430.	1609.	1788.	2146.	2503.	2861.
	$I_{y\text{-}y}$	0.005	0.018	0.042	0.083	0.143	0.227	0.339	0.482	0.661	1.143	1.814	2.708
33	Wt.	4.851	7.276	9.702	12.13	14.55	16.98	19.40	21.83	24.25	29.11	33.96	38.81
	Area	4.125	6.188	8.250	10.31	12.38	14.44	16.50	18.56	20.63	24.75	28.88	33.00
	$I_{x\text{-}x}$	374.3	561.5	748.7	935.9	1123.	1310.	1497.	1685.	1872.	2246.	2620.	2995.
	$I_{y\text{-}y}$	0.005	0.018	0.043	0.084	0.145	0.230	0.344	0.489	0.671	1.160	1.842	2.750
33½	Wt.	4.925	7.386	9.849	12.31	14.77	17.24	19.70	22.16	24.63	29.55	34.47	39.40
	Area	4.188	6.281	8.375	10.47	12.56	14.66	16.75	18.84	20.94	25.13	29.31	33.50
	$I_{x\text{-}x}$	391.6	587.4	783.2	979.0	1175.	1371.	1566.	1762.	1958.	2350.	2741.	3133.
	$I_{y\text{-}y}$	0.005	0.018	0.044	0.085	0.147	0.234	0.349	0.497	0.682	1.178	1.870	2.792
34	Wt.	4.998	7.497	9.996	12.50	14.99	17.49	19.99	22.49	24.99	29.99	34.99	39.98
	Area	4.250	6.375	8.500	10.63	12.75	14.88	17.00	19.13	21.25	25.50	29.75	34.00
	$I_{x\text{-}x}$	409.4	614.1	818.8	1024.	1228.	1433.	1638.	1842.	2047.	2457.	2866.	3275.
	$I_{y\text{-}y}$	0.006	0.019	0.044	0.086	0.149	0.237	0.354	0.504	0.692	1.195	1.898	2.833
34½	Wt.	5.072	7.608	10.14	12.68	15.22	17.75	20.29	22.83	25.35	30.43	35.50	40.57
	Area	4.313	6.469	8.625	10.78	12.94	15.09	17.25	19.41	21.56	25.88	30.19	34.50
	$I_{x\text{-}x}$	427.8	641.6	855.5	1069.	1283.	1497.	1711.	1925.	2139.	2567.	2994.	3422.
	$I_{y\text{-}y}$	0.006	0.019	0.045	0.088	0.152	0.241	0.359	0.512	0.702	1.213	1.926	2.875
35	Wt.	5.145	7.718	10.29	12.86	15.44	18.01	20.58	23.15	25.72	30.87	36.02	41.16
	Area	4.375	6.563	8.750	10.94	13.13	15.31	17.50	19.69	21.88	26.25	30.63	35.00
	$I_{x\text{-}x}$	446.6	669.9	893.2	1117.	1340.	1563.	1786.	2010.	2233.	2680.	3126.	3573.
	$I_{y\text{-}y}$	0.006	0.019	0.046	0.089	0.154	0.244	0.365	0.519	0.712	1.230	1.954	2.917
35½	Wt.	5.219	7.827	10.44	13.04	15.65	18.26	20.87	23.48	26.10	31.32	36.53	41.75
	Area	4.438	6.656	8.875	11.09	13.31	15.53	17.75	19.97	22.19	26.63	31.06	35.50
	$I_{x\text{-}x}$	466.0	699.0	932.1	1165.	1398.	1631.	1864.	2097.	2330.	2796.	3262.	3728.
	$I_{y\text{-}y}$	0.006	0.020	0.046	0.090	0.156	0.248	0.370	0.527	0.722	1.248	1.982	2.958

TABLE 54 rectangles **Elements of Sections**

Continued

All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

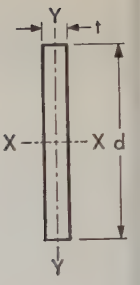
Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

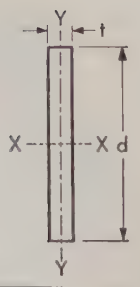
$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$



Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
36	Wt.	5.292	7.938	10.58	13.23	15.88	18.52	21.17	23.81	26.46	31.75	37.04	42.34
	Area	4.500	6.750	9.000	11.25	13.50	15.75	18.00	20.25	22.50	27.00	31.50	36.00
	$I_{x\text{-}x}$	486.0	729.0	972.0	1215.	1458.	1701.	1944.	2187.	2430.	2916.	3402.	3888.
	$I_{y\text{-}y}$	0.006	0.020	0.047	0.092	0.158	0.251	0.375	0.534	0.732	1.266	2.010	3.000
36½	Wt.	5.366	8.049	10.73	13.42	16.10	18.78	21.46	24.14	26.82	32.20	37.56	42.92
	Area	4.563	6.844	9.125	11.41	13.69	15.97	18.25	20.53	22.81	27.38	31.94	36.50
	$I_{x\text{-}x}$	506.5	759.8	1013.	1266.	1520.	1773.	2026.	2279.	2533.	3039.	3546.	4052.
	$I_{y\text{-}y}$	0.006	0.020	0.048	0.093	0.160	0.255	0.380	0.541	0.743	1.283	2.038	3.042
37	Wt.	5.439	8.158	10.88	13.60	16.32	19.04	21.76	24.48	27.20	32.63	38.08	43.51
	Area	4.625	6.938	9.250	11.56	13.88	16.19	18.50	20.81	23.13	27.75	32.38	37.00
	$I_{x\text{-}x}$	527.6	791.5	1055.	1319.	1583.	1847.	2111.	2374.	2638.	3166.	3693.	4221.
	$I_{y\text{-}y}$	0.006	0.020	0.048	0.094	0.163	0.258	0.385	0.549	0.753	1.301	2.066	3.083
37½	Wt.	5.513	8.268	11.03	13.78	16.53	19.30	22.05	24.80	27.57	33.08	38.58	44.10
	Area	4.688	7.031	9.375	11.72	14.06	16.41	18.75	21.09	23.44	28.13	32.81	37.50
	$I_{x\text{-}x}$	549.3	824.0	1099.	1373.	1648.	1923.	2197.	2472.	2747.	3296.	3845.	4395.
	$I_{y\text{-}y}$	0.006	0.021	0.049	0.095	0.165	0.262	0.391	0.556	0.763	1.318	2.094	3.125
38	Wt.	5.586	8.379	11.17	13.96	16.76	19.55	22.34	25.14	27.93	33.52	39.10	44.69
	Area	4.750	7.125	9.500	11.88	14.25	16.63	19.00	21.38	23.75	28.50	33.25	38.00
	$I_{x\text{-}x}$	571.6	857.4	1143.	1429.	1715.	2001.	2286.	2572.	2858.	3430.	4001.	4573.
	$I_{y\text{-}y}$	0.006	0.021	0.049	0.097	0.167	0.265	0.396	0.564	0.773	1.336	2.121	3.167
38½	Wt.	5.660	8.490	11.32	14.15	16.98	19.80	22.64	25.47	28.29	33.96	39.62	45.28
	Area	4.813	7.219	9.625	12.03	14.44	16.84	19.25	21.66	24.06	28.88	33.69	38.50
	$I_{x\text{-}x}$	594.4	891.7	1189.	1486.	1783.	2081.	2378.	2675.	2972.	3567.	4161.	4756.
	$I_{y\text{-}y}$	0.006	0.021	0.050	0.098	0.169	0.269	0.401	0.571	0.783	1.354	2.149	3.208
39	Wt.	5.733	8.599	11.47	14.33	17.20	20.07	22.93	25.80	28.66	34.40	40.14	45.86
	Area	4.875	7.313	9.750	12.19	14.63	17.06	19.50	21.94	24.38	29.25	34.13	39.00
	$I_{x\text{-}x}$	617.9	926.9	1236.	1545.	1854.	2163.	2472.	2781.	3090.	3707.	4325.	4943.
	$I_{y\text{-}y}$	0.006	0.021	0.051	0.099	0.171	0.272	0.406	0.578	0.793	1.371	2.177	3.250
39½	Wt.	5.807	8.709	11.61	14.51	17.42	20.32	23.23	26.13	29.04	34.84	40.64	46.45
	Area	4.938	7.406	9.875	12.34	14.81	17.28	19.75	22.22	24.69	29.63	34.56	39.50
	$I_{x\text{-}x}$	642.0	963.0	1284.	1605.	1926.	2247.	2568.	2889.	3210.	3852.	4494.	5136.
	$I_{y\text{-}y}$	0.006	0.022	0.051	0.100	0.174	0.276	0.411	0.586	0.804	1.389	2.205	3.292

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

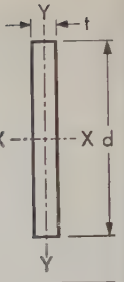
Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
40	Wt.	5.880	8.820	11.76	14.70	17.64	20.58	23.52	26 46	29.40	35.28	41.16	47.04
	Area	5.000	7.500	10.00	12.50	15.00	17.50	20.00	22.50	25.00	30.00	35.00	40.00
	$I_{x\text{-}x}$	666.7	1000.	1333.	1667.	2000.	2333.	2667.	3000	3333.	4000.	4667.	5333.
	$I_{y\text{-}y}$	0.007	0.022	0.052	0.102	0.176	0.279	0.417	0.593	0.814	1.406	2.233	3.333
40½	Wt.	5.954	8.931	11.91	14.89	17.86	20.84	23.81	26.79	29.76	35.73	41.68	47.63
	Area	5.063	7.594	10.13	12.66	15.19	17 72	20.25	22.78	25.31	30.38	35.44	40.50
	$I_{x\text{-}x}$	692.0	1038.	1384.	1730.	2076.	2422.	2768.	3114.	3460.	4152.	4844.	5536.
	$I_{y\text{-}y}$	0.007	0.022	0.053	0.103	0.178	0.283	0.422	0.601	0.824	1.424	2.261	3.375
41	Wt.	6.027	9.040	12.05	15.07	18.08	21 09	24 11	27.12	30.14	36.16	42.19	48.22
	Area	5.125	7.688	10.25	12.81	15.38	17.94	20.50	23.06	25.63	30.75	35.88	41.00
	$I_{x\text{-}x}$	717.9	1077	1436.	1795.	2154	2513.	2872	3231.	3590	4308.	5026.	5743.
	$I_{y\text{-}y}$	0.007	0.023	0.053	0.104	0.180	0.286	0.427	0.608	0.834	1.441	2.289	3.417
41½	Wt.	6 101	9.150	12.21	15.25	18.30	21.36	24.40	27.45	30.51	36.61	42.70	48.80
	Area	5.188	7.781	10.38	12.97	15.56	18 16	20 75	23.34	25.94	31 13	36 31	41.50
	$I_{x\text{-}x}$	744.5	1117.	1489.	1861.	2234.	2606.	2978.	3350.	3723.	4467.	5212.	5956.
	$I_{y\text{-}y}$	0.007	0.023	0.054	0.106	0.182	0.290	0.432	0.616	0.844	1.459	2.317	3.458
42	Wt.	6.174	9.261	12.35	15.44	18.52	21.61	24.70	27.78	30.87	37.84	43.22	49.39
	Area	5.250	7.875	10.50	13.13	15.75	18 38	21.00	23.63	26.25	31.50	36.75	42.00
	$I_{x\text{-}x}$	771.8	1158.	1544.	1929.	2315.	2701.	3087.	3473.	3859.	4631.	5402.	6174.
	$I_{y\text{-}y}$	0.007	0.023	0.055	0.107	0.185	0.293	0.438	0.623	0.854	1.477	2.345	3.500
42½	Wt.	6.248	9.372	12.50	15.62	18.75	21.86	24.99	28.12	31.23	37.49	43.74	49.98
	Area	5.313	7.969	10.63	13.28	15.94	18.59	21.25	23.91	26.56	31.88	37.19	42.50
	$I_{x\text{-}x}$	799.6	1199.	1599.	1999.	2399.	2799.	3199.	3598.	3998.	4798.	5598.	6397.
	$I_{y\text{-}y}$	0.007	0.023	0.055	0.108	0.187	0.297	0.443	0.630	0.865	1.494	2.373	3.542
43	Wt.	6.321	9.482	12.64	15.80	18.96	22.12	25.28	28.44	31.60	37.93	44.25	50.57
	Area	5.375	8.063	10.75	13.44	16.13	18.81	21.50	24.19	26.88	32.25	37.63	43.00
	$I_{x\text{-}x}$	828.2	1242.	1656.	2070.	2485.	2899.	3313.	3727	4141.	4969	5797.	6626.
	$I_{y\text{-}y}$	0.007	0.024	0.056	0.109	0.189	0.300	0.448	0.638	0.875	1.512	2.401	3.583
43½	Wt.	6.395	9.591	12.79	15.98	19.18	22.38	25.58	28.78	31.98	38.37	44.76	51.16
	Area	5.438	8.156	10.88	13.59	16.31	19.03	21.75	24.47	27.19	32.63	38.06	43.50
	$I_{x\text{-}x}$	857.4	1286.	1715.	2144.	2572.	3001.	3430.	3858.	4287.	5145.	6002.	6859.
	$I_{y\text{-}y}$	0.007	0.024	0.057	0.111	0.191	0.304	0.453	0.645	0.885	1.529	2.428	3.625

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
44	Wt.	6.468	9.702	12.94	16.17	19.40	22.64	25.87	29.11	32.34	38.81	45.28	51.74
	Area	5.500	8.250	11.00	13.75	16.50	19.25	22.00	24.75	27.50	33.00	38.50	44.00
	$I_{x\text{-}x}$	887.3	1331.	1775.	2218.	2662.	3106.	3549.	3993.	4437.	5324.	6211.	7099.
	$I_{y\text{-}y}$	0.007	0.024	0.057	0.112	0.193	0.307	0.458	0.653	0.895	1.547	2.456	3.667
44½	Wt.	6.542	9.813	13.09	16.36	19.63	22.90	26.17	29.44	32.70	39.25	45.79	52.33
	Area	5.563	8.344	11.13	13.91	16.69	19.47	22.25	25.03	27.81	33.38	38.94	44.50
	$I_{x\text{-}x}$	917.9	1377.	1836.	2295.	2754.	3213.	3672.	4131.	4590.	5508.	6426.	7343.
	$I_{y\text{-}y}$	0.007	0.024	0.058	0.113	0.196	0.311	0.464	0.660	0.905	1.564	2.484	3.708
45	Wt.	6.615	9.922	13.23	16.54	19.84	23.15	26.46	29.77	33.08	39.69	46.31	52.92
	Area	5.625	8.438	11.25	14.06	16.88	19.69	22.50	25.31	28.13	33.75	39.38	45.00
	$I_{x\text{-}x}$	949.2	1424.	1898.	2373.	2848.	3322.	3797.	4271.	4746.	5695.	6645.	7594.
	$I_{y\text{-}y}$	0.007	0.025	0.059	0.114	0.198	0.314	0.469	0.667	0.916	1.582	2.512	3.750
45½	Wt.	6.689	10.03	13.38	16.72	20.06	23.41	26.75	30.09	33.45	40.14	46.82	53.51
	Area	5.688	8.531	11.38	14.22	17.06	19.91	22.75	25.59	28.44	34.13	39.81	45.50
	$I_{x\text{-}x}$	981.2	1472.	1962.	2453.	2944.	3434.	3925.	4415.	4906.	5887.	6868.	7850.
	$I_{y\text{-}y}$	0.007	0.025	0.059	0.116	0.200	0.318	0.474	0.675	0.926	1.600	2.540	3.792
46	Wt.	6.762	10.14	13.52	16.90	20.29	23.67	27.05	30.43	33.81	40.57	47.33	54.10
	Area	5.750	8.625	11.50	14.38	17.25	20.13	23.00	25.88	28.75	34.50	40.25	46.00
	$I_{x\text{-}x}$	1014.	1521.	2028.	2535.	3042.	3549.	4056.	4563.	5070.	6084.	7097.	8111.
	$I_{y\text{-}y}$	0.007	0.025	0.060	0.117	0.202	0.321	0.479	0.682	0.936	1.617	2.568	3.833
46½	Wt.	6.836	10.25	13.68	17.09	20.51	23.92	27.34	30.76	34.17	41.02	47.85	54.68
	Area	5.813	8.719	11.63	14.53	17.44	20.34	23.25	26.16	29.06	34.88	40.69	46.50
	$I_{x\text{-}x}$	1047.	1571.	2095.	2618.	3142.	3666.	4189.	4713.	5237.	6284.	7331.	8379.
	$I_{y\text{-}y}$	0.008	0.026	0.061	0.118	0.204	0.324	0.484	0.690	0.946	1.635	2.596	3.875
47	Wt.	6.909	10.36	13.82	17.27	20.73	24.18	27.64	31.09	34.54	41.54	48.37	55.27
	Area	5.875	8.813	11.75	14.69	17.63	20.56	23.50	26.44	29.38	35.25	41.13	47.00
	$I_{x\text{-}x}$	1081.	1622.	2163.	2704.	3244.	3785.	4326.	4867.	5407.	6489.	7570.	8652.
	$I_{y\text{-}y}$	0.008	0.026	0.061	0.120	0.207	0.328	0.490	0.697	0.956	1.652	2.624	3.917
48	Wt.	7.056	10.58	14.11	17.64	21.17	24.70	28.22	31.75	35.28	42.34	49.39	56.44
	Area	6.000	9.000	12.00	15.00	18.00	21.00	24.00	27.00	30.00	36.00	42.00	48.00
	$I_{x\text{-}x}$	1152.	1728.	2304.	2880.	3456.	4032.	4608.	5184.	5760.	6912.	8064.	9216.
	$I_{y\text{-}y}$	0.008	0.026	0.063	0.122	0.211	0.335	0.500	0.712	0.977	1.687	2.680	4.000

TABLE 54

rectangles

Elements of Sections

Continued

All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2},\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

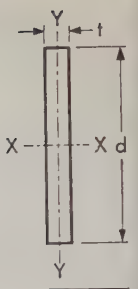
Radius of Gyration:

$$r_{x\text{-}x}=0.289\,d;\quad r_{y\text{-}y}=0.289\,t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
49	Wt.	7.203	10.80	14.41	18.01	21.61	25.21	28.81	32.41	36.02	43.22	50.43	57.62
	Area	6.125	9.188	12.25	15.31	18.38	21.44	24.50	27.56	30.63	36.75	42.88	49.00
	$I_{x\text{-}x}$	1226.	1838.	2451.	3064.	3677.	4289.	4902.	5515.	6128.	7353.	8579.	9804.
	$I_{y\text{-}y}$	0.008	0.027	0.064	0.125	0.215	0.342	0.510	0.727	0.997	1.723	2.736	4.083
50	Wt.	7.350	11.82	14.70	18.38	22.05	25.72	29.40	33.08	36.75	44.10	51.45	58.80
	Area	6.250	9.375	12.50	15.63	18.75	21.88	25.00	28.13	31.25	37.50	43.75	50.00
	$I_{x\text{-}x}$	1302.	1953.	2604.	3255.	3906.	4557.	5208.	5859.	6510.	7813	9115.	10417
	$I_{y\text{-}y}$	0.008	0.027	0.065	0.127	0.220	0.349	0.521	0.742	1.017	1.758	2.791	4.167
51	Wt.	7.498	11.24	14.99	18.74	22.49	26.24	29.99	33.74	37.48	44.98	52.48	59.98
	Area	6.375	9.563	12.75	15.94	19.13	22.31	25.50	28.69	31.88	38.25	44.63	51.00
	$I_{x\text{-}x}$	1382.	2073.	2764.	3454.	4145.	4836.	5527.	6218.	6909.	8291.	9672.	11054
	$I_{y\text{-}y}$	0.008	0.028	0.066	0.130	0.224	0.356	0.531	0.756	1.038	1.793	2.847	4.250
52	Wt.	7.644	11.47	15.29	19.11	22.93	26.75	30.58	34.40	38.22	45.86	53.51	61.15
	Area	6.500	9.750	13.00	16.25	19.50	22.75	26.00	29.25	32.50	39.00	45.50	52.00
	$I_{x\text{-}x}$	1465.	2197.	2929.	3662.	4394	5126.	5859.	6591.	7323.	8788.	10253	11717
	$I_{y\text{-}y}$	0.008	0.029	0.068	0.132	0.229	0.363	0.542	0.771	1.058	1.828	2.903	4.333
53	Wt.	7.791	11.69	15.58	19.48	23.37	27.27	31.16	35.06	38.96	46.75	54.54	62.33
	Area	6.625	9.938	13.25	16.56	19.88	23.19	26.50	29.81	33.13	39.75	46.38	53.00
	$I_{x\text{-}x}$	1551.	2326.	3102.	3877.	4652.	5428.	6203.	6979.	7754.	9305.	10856	12406
	$I_{y\text{-}y}$	0.009	0.029	0.069	0.135	0.233	0.370	0.552	0.786	1.078	1.863	2.959	4.417
54	Wt.	7.938	11.91	15.88	19.84	23.81	27.78	31.75	35.72	39.69	47.63	55.57	63.50
	Area	6.750	10.13	13.50	16.88	20.25	23.63	27.00	30.38	33.75	40.50	47.25	54.00
	$I_{x\text{-}x}$	1640.	2460.	3281.	4101.	4921.	5741.	6561.	7381.	8201.	9842.	11482	13122
	$I_{y\text{-}y}$	0.009	0.030	0.070	0.137	0.237	0.377	0.563	0.801	1.099	1.898	3.015	4.500
55	Wt.	8.085	12.13	16.17	20.21	24.26	28.30	32.34	36.38	40.42	48.51	56.60	64.68
	Area	6.875	10.31	13.75	17.19	20.63	24.06	27.50	30.94	34.38	41.25	48.13	55.00
	$I_{x\text{-}x}$	1733.	2600.	3466.	4333.	5199.	6066.	6932.	7799.	8665.	10398	12132	13865
	$I_{y\text{-}y}$	0.009	0.030	0.072	0.140	0.242	0.384	0.573	0.816	1.119	1.934	3.070	4.583
56	Wt.	8.232	12.35	16.46	20.58	24.70	28.81	32.93	37.04	41.96	49.39	57.62	65.86
	Area	7.000	10.50	14.00	17.50	21.00	24.50	28.00	31.50	35.00	42.00	49.00	56.00
	$I_{x\text{-}x}$	1829.	2744.	3659.	4573.	5488.	6403.	7317.	8232.	9147.	10976	12805	14635
	$I_{y\text{-}y}$	0.009	0.031	0.073	0.142	0.246	0.391	0.583	0.831	1.139	1.969	3.126	4.667

TABLE 54 rectangles **Elements of Sections**

Continued



All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
57	Wt.	8.379	12.57	16.76	20.95	25.14	29.33	33.52	37.71	41.90	50.27	58.66	67.03
	Area	7.125	10.69	14.25	17.81	21.38	24.94	28.50	32.06	35.63	42.75	49.88	57.00
	$I_{x\text{-}x}$	1929.	2894.	3858.	4823.	5787.	6752.	7716.	8681.	9645.	11575	13504	15433
	$I_{y\text{-}y}$	0.009	0.031	0.074	0.145	0.250	0.398	0.594	0.845	1.160	2.004	3.182	4.750
58	Wt.	8.526	12.79	17.05	21.32	25.58	29.84	34.10	38.37	42.63	51.16	59.68	68.21
	Area	7.250	10 88	14.50	18.13	21.75	25.38	29.00	32.63	36.25	43.50	50.75	58.00
	$I_{x\text{-}x}$	2032.	3049.	4065.	5081.	6097.	7113.	8130.	9146.	10162	12195	14227	16259
	$I_{y\text{-}y}$	0.009	0.032	0.076	0.148	0.255	0.405	0.604	0.860	1.180	2.039	3.238	4.833
59	Wt.	8.673	13.01	17.35	21.68	26.02	30.36	34.69	39.03	43.36	52.04	60 72	69.38
	Area	7.375	11.06	14.75	18.44	22.13	25.81	29.50	33.19	36.88	44.25	51.63	59.00
	$I_{x\text{-}x}$	2139.	3209.	4279.	5348.	6418.	7488.	8557.	9627.	10697	12836	14976	17115
	$I_{y\text{-}y}$	0.010	0.032	0.077	0.150	0.259	0.412	0.615	0.875	1.200	2.074	3.294	4.917
60	Wt.	8.820	13.23	17.64	22.05	26.46	30.87	35.28	39.69	44 10	52.92	61.74	70.56
	Area	7.500	11.25	15.00	18.75	22.50	26.25	30.00	33.75	37.50	45.00	52.50	60.00
	$I_{x\text{-}x}$	2250.	3375.	4500.	5625.	6750	7875	9000.	10125	11250	13500	15750	18000
	$I_{y\text{-}y}$	0.010	0.033	0.078	0.153	0.264	0.419	0.625	0.890	1.221	2.109	3.350	5.000
61	Wt.	8.967	13.45	17.93	22.42	26.90	31.38	35.87	40 35	44.84	53 80	62 77	71.74
	Area	7.625	11.44	15.25	19.06	22.88	26.69	30.50	34.31	38.13	45.75	53.38	61.00
	$I_{x\text{-}x}$	2364.	3547.	4729.	5911.	7093.	8275.	9458.	10640	11822	14186	16551	18915
	$I_{y\text{-}y}$	0.010	0.034	0.079	0.155	0.268	0.426	0.635	0.905	1.241	2.145	3.405	5.083
62	Wt.	9.114	13.67	18.23	22.78	27.34	31.90	36.46	41.01	45.57	54.68	63 80	72.91
	Area	7.750	11.63	15.50	19.38	23.25	27.13	31.00	34.88	38.75	46.50	54.25	62.00
	$I_{x\text{-}x}$	2483.	3724.	4965.	6206.	7448.	8689.	9930.	11172	12413	14896	17378	19861
	$I_{y\text{-}y}$	0.010	0.034	0.081	0.158	0.272	0.433	0.646	0.920	1.261	2.180	3.461	5.167
63	Wt.	9.261	13.89	18.52	23.15	27.78	32.41	37.04	41.67	46.30	55.57	64.83	74.09
	Area	7.875	11.81	15.75	19.69	23.63	27.56	31.50	35.44	39.38	47.25	55.13	63.00
	$I_{x\text{-}x}$	2605.	3907.	5209.	6512.	7814.	9116.	10419	11721	13023	15628	18233	20837
	$I_{y\text{-}y}$	0.010	0.035	0.082	0.160	0.277	0.440	0.656	0.934	1.282	2.215	3.517	5.250
64	Wt.	9.408	14.11	18.82	23.52	28.22	32.93	37.63	42.33	47.04	56.45	65.86	75.26
	Area	8.000	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	48.00	56.00	64.00
	$I_{x\text{-}x}$	2731.	4096.	5461.	6827.	8192.	9557.	10923	12288	13653	16384	19115	21845
	$I_{y\text{-}y}$	0.010	0.035	0.083	0.163	0.281	0.447	0.667	0.949	1.302	2.250	3.573	5.333

TABLE 54 rectangles **Elements of Sections**

Concluded

All dimensions in inches.

Weight in pounds per foot.

Area in square inches.

I = Moment of Inertia in in.⁴

Formulas

Section Modulus:

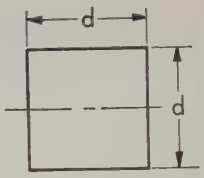
$$S_{x\text{-}x}=\frac{I_{x\text{-}x}}{d/2};\quad S_{y\text{-}y}=\frac{I_{y\text{-}y}}{t/2}$$

Radius of Gyration:

$$r_{x\text{-}x}=0.289\ d;\quad r_{y\text{-}y}=0.289\ t$$

Depth, d		Thickness, t											
		1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
65	Wt.	9.555	14.33	19.11	23.89	28.66	33.44	38.22	43.00	47.78	57.33	66.89	76.44
	Area	8.125	12.19	16.25	20.31	24.38	28.44	32.50	36.56	40.63	48.75	56.88	65.00
	$I_{x\text{-}x}$	2861.	4291.	5721.	7152.	8582.	10012	11443	12873	14303	17164	20025	22885
	$I_{y\text{-}y}$	0.011	0.036	0 085	0.165	0.286	0.454	0.677	0.964	1.322	2.285	3.629	5.417
66	Wt.	9.702	14.55	19.40	24.26	29.11	33.96	38.81	43.66	48.51	58.21	67.91	77.62
	Area	8.250	12.38	16 50	20.63	24.75	28 88	33.00	37.13	41.25	49.50	57.75	66.00
	$I_{x\text{-}x}$	2995.	4492.	5990.	7487.	8948.	10482	11979	13476	14974	17969	20963	23958
	$I_{y\text{-}y}$	0.011	0.036	0.086	0.168	0.290	0.461	0.688	0.979	1.343	2.320	3.685	5.500
67	Wt.	9.849	14.77	19.70	24.62	29.55	34.47	39.40	44.32	49.24	59.09	68.95	78.79
	Area	8.375	12.56	16.75	20.94	25.13	29.31	33.50	37.69	41.88	50.25	58.63	67.00
	$I_{x\text{-}x}$	3133.	4699.	6266.	7832.	9399.	10965	12532	14098	15665	18798	21931	25064
	$I_{y\text{-}y}$	0.011	0.037	0.087	0.170	0.294	0.468	0.698	0.994	1.363	2.355	3.740	5.583
68	Wt.	9.996	14.99	19.99	24.99	29.99	34.99	39.98	44.98	49.98	59.98	69.97	79.97
	Area	8.500	12.75	17.00	21.25	25.50	29.75	34.00	38.25	42.50	51.00	59.50	68.00
	$I_{x\text{-}x}$	3275.	4913.	6551.	8188.	9826.	11464	13101	14739	16377	19652	22927	26203
	$I_{y\text{-}y}$	0.011	0.037	0.089	0.173	0.299	0.475	0.708	1.009	1.383	2.391	3.796	5.667
69	Wt.	10.14	15.21	20.29	25.36	30.43	35.50	40.57	45.64	50.72	60.88	71.01	81.14
	Area	8.625	12.94	17.25	21.56	25.88	30.19	34.50	38.81	43.13	51.75	60.38	69.00
	$I_{x\text{-}x}$	3422.	5133.	6844.	8555.	10266	11977	13688	15399	17110	20532	23954	27376
	$I_{y\text{-}y}$	0.011	0.038	0.090	0.175	0.303	0.482	0.719	1.023	1.404	2.426	3.852	5.750
70	Wt.	10.29	15.44	20.58	25.72	30.87	36.02	41.16	46.31	51.45	61.74	72.03	82.32
	Area	8.750	13.13	17.50	21.88	26.25	30.63	35.00	39.38	43.75	52.50	61.25	70.00
	$I_{x\text{-}x}$	3573.	5359.	7146.	8932.	10719	12505	14292	16078	17865	21438	25010	28583
	$I_{y\text{-}y}$	0.011	0.038	0.091	0.178	0.308	0.488	0.729	1.038	1.424	2.461	3.908	5.833
71	Wt.	10.44	15.66	20.87	26.09	31.31	36.53	41.75	46.97	52.18	62.62	73.06	83.50
	Area	8.875	13.31	17.75	22.19	26.63	31.06	35.50	39.94	44.38	53.25	62.13	71.00
	$I_{x\text{-}x}$	3728.	5592.	7456.	9321.	11185	13049	14913	16777	18641	22369	26098	29826
	$I_{y\text{-}y}$	0.012	0.039	0.092	0.181	0.312	0.495	0.740	1.053	1.444	2.496	3.964	5.917
72	Wt.	10.58	15.88	21.17	26.46	31.75	37.04	42.34	47.63	52.92	63.50	74.09	84.67
	Area	9.000	13.50	18.00	22.50	27.00	31.50	36.00	40.50	45.00	54.00	63.00	72.00
	$I_{x\text{-}x}$	3888.	5832.	7776.	9720.	11664	13608	15552	17496	19440	23328	27216	31104
	$I_{y\text{-}y}$	0.012	0.040	0.094	0.183	0.316	0.502	0.750	1.068	1.465	2.531	4.020	6.000

TABLE
55 square bar — Elements of Sections



All dimensions in inches
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}

Formulas

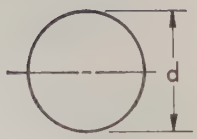
Section Modulus: $S = \frac{I}{d/2}$

Radius of Gyration: $r = 0.289\,d$

Size, d	Weight	Area	I	Size, d	Weight	Area	I
3/8	0.165	0.141	0.002	15/16	2.026	1.723	0.247
13/32	0.194	0.165	0.002	1 11/32	2.123	1.806	0.272
7/16	0.225	0.191	0.003				
15/32	0.258	0.220	0.004	1 3/8	2.223	1.891	0.298
				1 13/32	2.326	1.978	0.326
1/2	0.294	0.250	0.005	1 7/16	2.430	2.066	0.356
17/32	0.332	0.282	0.007	1 15/32	2.537	2.157	0.388
9/16	0.372	0.316	0.008				
19/32	0.415	0.353	0.010	1 1/2	2.646	2.250	0.422
				1 5/8	3.105	2.641	0.581
5/8	0.459	0.391	0.013	1 3/4	3.602	3.062	0.782
21/32	0.506	0.431	0.015	1 7/8	4.134	3.516	1.030
11/16	0.556	0.473	0.019				
23/32	0.608	0.517	0.022	2	4.704	4.000	1.333
				2 1/8	5.310	4.516	1.699
3/4	0.662	0.562	0.026	2 1/4	5.954	5.062	2.136
25/32	0.718	0.610	0.031	2 3/8	6.633	5.641	2.651
13/16	0.776	0.660	0.036				
27/32	0.837	0.712	0.042	2 1/2	7.350	6.250	3.255
				2 5/8	8.103	6.891	3.957
7/8	0.900	0.766	0.049	2 3/4	8.894	7.562	4.766
29/32	0.966	0.821	0.056	2 7/8	9.720	8.266	5.693
15/16	1.034	0.879	0.064				
31/32	1.104	0.938	0.073	3	10.58	9.000	6.750
				3 1/8	11.48	9.766	7.947
1	1.176	1.000	0.083	3 1/4	12.42	10.56	9.297
1 1/32	1.251	1.063	0.094	3 3/8	13.40	11.39	10.81
1 1/16	1.328	1.129	0.106				
1 3/32	1.407	1.196	0.119	3 1/2	14.41	12.25	12.51
				3 5/8	15.45	13.14	14.39
1 1/8	1.488	1.266	0.133	3 3/4	16.54	14.06	16.48
1 5/32	1.572	1.337	0.149	3 7/8	17.66	15.02	18.79
1 3/16	1.658	1.410	0.166				
1 7/32	1.747	1.485	0.184	4	18.82	16.00	21.33
				4 1/2	23.81	20.25	34.17
1 1/4	1.838	1.562	0.203	5	29.40	25.00	52.08
1 9/32	1.931	1.642	0.225	5 1/2	35.57	30.25	76.26

TABLE 56

Elements of Sections



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}

Formulas

Section Modulus: $S = \frac{I}{d/2}$

Radius of Gyration: $r = d/4$

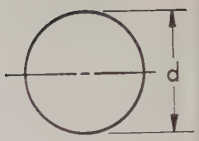
Dia., d	Weight	Area	I	Dia., d	Weight	Area	I
3/8	0.130	0.110	0.001	1 1/4	1.443	1.227	0.120
13/32	0.152	0.130	0.001	1 9/32	1.516	1.289	0.132
7/16	0.177	0.150	0.002	1 5/16	1.591	1.353	0.146
15/32	0.203	0.173	0.002	1 11/32	1.668	1.418	0.160
1/2	0.231	0.196	0.003	1 3/8	1.746	1.485	0.175
17/32	0.261	0.222	0.004	1 13/32	1.827	1.553	0.192
9/16	0.292	0.249	0.005	1 7/16	1.909	1.623	0.210
19/32	0.326	0.277	0.006	1 15/32	1.992	1.694	0.228
5/8	0.361	0.307	0.007	1 1/2	2.078	1.767	0.248
21/32	0.398	0.338	0.009	1 9/16	2.255	1.917	0.293
11/16	0.437	0.371	0.011	1 5/8	2.439	2.074	0.342
23/32	0.477	0.406	0.013	1 11/16	2.630	2.237	0.398
3/4	0.520	0.442	0.016	1 3/4	2.829	2.405	0.460
25/32	0.564	0.479	0.018	1 13/16	3.034	2.580	0.530
13/16	0.610	0.518	0.021	1 7/8	3.247	2.761	0.607
27/32	0.658	0.559	0.025	1 15/16	3.467	2.948	0.692
7/8	0.707	0.601	0.029	2	3.695	3.142	0.785
29/32	0.759	0.645	0.033	2 1/16	3.929	3.341	0.888
15/16	0.812	0.690	0.038	2 1/8	4.171	3.547	1.001
31/32	0.867	0.737	0.043	2 3/16	4.420	3.758	1.124
1	0.924	0.785	0.049	2 1/4	4.676	3.976	1.258
1 1/32	0.982	0.835	0.056	2 5/16	4.939	4.200	1.404
1 1/16	1.043	0.887	0.063	2 3/8	5.210	4.430	1.562
1 3/32	1.105	0.940	0.070	2 7/16	5.488	4.666	1.733
1 1/8	1.169	0.994	0.079	2 1/2	5.773	4.909	1.917
1 5/32	1.235	1.050	0.088	2 9/16	6.065	5.157	2.117
1 3/16	1.302	1.108	0.097	2 5/8	6.364	5.412	2.331
1 7/32	1.372	1.167	0.108	2 11/16	6.671	5.673	2.561

Continued on next page

TABLE 56 rod

Elements of Sections

Concluded



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.
I = Moment of Inertia in in.^{4}

Formulas

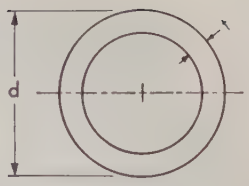
Section Modulus: $S = \frac{I}{d/2}$

Radius of Gyration: $r = d/4$

Dia., d	Weight	Area	I	Dia., d	Weight	Area	I
2 3/4	6.985	5.940	2.807	4 1/2	18.70	15.90	20.13
2 13/16	7.306	6.213	3.071	4 9/16	19.23	16.35	21.27
2 7/8	7.634	6.492	3.354	4 5/8	19.76	16.80	22.46
2 15/16	7.970	6.777	3.655	4 11/16	20.29	17.26	23.70
3	8.313	7.069	3.976	4 3/4	20.84	17.72	24.99
3 1/16	8.663	7.366	4.318	4 13/16	21.39	18.19	26.33
3 1/8	9.020	7.670	4.681	4 7/8	21.95	18.67	27.72
3 3/16	9.384	7.980	5.067	4 15/16	22.52	19.15	29.17
3 1/4	9.756	8.296	5.476	5	23.09	19.64	30.68
3 5/16	10.13	8.618	5.910	5 1/8	24.26	20.63	33.86
3 3/8	10.52	8.946	6.369	5 1/4	25.46	21.65	37.29
3 7/16	10.91	9.281	6.854	5 3/8	26.68	22.69	40.97
3 1/2	11.31	9.621	7.366	5 1/2	27.94	23.76	44.92
3 9/16	11.72	9.968	7.907	5 5/8	29.22	24.85	49.14
3 5/8	12.14	10.32	8.476	5 3/4	30.54	25.97	53.66
3 11/16	12.56	10.68	9.076	5 7/8	31.88	27.11	58.48
3 3/4	12.99	11.04	9.707	6	33.25	28.27	63.62
3 13/16	13.43	11.42	10.37	6 1/4	36.08	30.68	74.90
3 7/8	13.87	11.79	11.07	6 1/2	39.02	33.18	87.62
3 15/16	14.32	12.18	11.80	6 3/4	42.08	35.78	101.9
4	14.78	12.57	12.57	7	45.26	38.48	117.9
4 1/16	15.24	12.96	13.37	7 1/4	48.55	41.28	135.6
4 1/8	15.72	13.36	14.21	7 1/2	51.95	44.18	155.3
4 3/16	16.20	13.77	15.09	7 3/4	55.48	47.17	177.1
4 1/4	16.68	14.19	16.01	8	59.11	50.27	201.1
4 5/16	17.18	14.61	16.98				
4 3/8	17.68	15.03	17.98				
4 7/16	18.19	15.47	19.03				

TABLE

57 Round Tubes — Elements of Sections



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.

Diameter, d	½					¾				
Thickness, t	1/32	1/16	3/32	1/8	5/32	1/32	1/16	3/32	1/8	3/16
Weight	0.054	0.101	0.141	0.173	0.199	0.083	0.159	0.227	0.288	0.389
Area	0.046	0.086	0.120	0.147	0.169	0.071	0.135	0.193	0.245	0.331
I	0.001	0.002	0.003	0.003	0.003	0.005	0.008	0.011	0.012	0.015
S	0.005	0.008	0.010	0.012	0.012	0.012	0.021	0.028	0.033	0.039
r	0.166	0.156	0.147	0.140	0.134	0.254	0.244	0.234	0.225	0.210

Diameter, d	1					1¼				
Thickness, t	1/32	1/16	1/8	3/16	1/4	1/32	1/16	1/8	3/16	1/4
Weight	0.112	0.216	0.405	0.563	0.693	0.141	0.274	0.520	0.736	0.923
Area	0.095	0.184	0.344	0.479	0.589	0.120	0.233	0.442	0.626	0.785
I	0.011	0.020	0.034	0.042	0.046	0.022	0.041	0.071	0.091	0.104
S	0.022	0.041	0.067	0.083	0.092	0.036	0.066	0.113	0.146	0.167
r	0.342	0.332	0.313	0.295	0.280	0.431	0.420	0.400	0.381	0.364

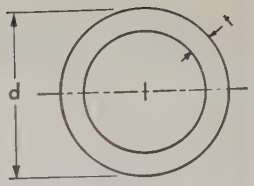
Diameter, d	1½					1¾				
Thickness, t	1/32	1/16	1/8	3/16	1/4	1/32	1/16	1/8	3/16	1/4
Weight	0.169	0.332	0.635	0.909	1.155	0.199	0.389	0.750	1.082	1.385
Area	0.144	0.282	0.540	0.773	0.982	0.169	0.331	0.638	0.920	1.178
I	0.039	0.073	0.129	0.170	0.199	0.062	0.118	0.212	0.285	0.341
S	0.052	0.097	0.172	0.227	0.266	0.071	0.135	0.242	0.326	0.389
r	0.519	0.509	0.488	0.469	0.451	0.608	0.597	0.576	0.556	0.538

Diameter, d	2					2¼				
Thickness, t	1/16	1/8	3/16	1/4	5/16	1/16	1/8	3/16	1/4	5/16
Weight	0.447	0.865	1.256	1.616	1.949	0.506	0.981	1.429	1.847	2.237
Area	0.380	0.736	1.068	1.374	1.657	0.430	0.834	1.215	1.571	1.902
I	0.179	0.325	0.443	0.537	0.610	0.257	0.473	0.651	0.798	0.916
S	0.179	0.325	0.443	0.537	0.610	0.229	0.420	0.579	0.709	0.814
r	0.685	0.664	0.644	0.625	0.607	0.774	0.753	0.732	0.713	0.694

Continued on next page

TABLE **57** round tubes **Elements of Sections**

Continued



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.

Diameter, d	2½					2¾				
Thickness, t	1/16	1/8	3/16	1/4	5/16	1/16	1/8	3/16	1/4	5/16
Weight	0.563	1.097	1.602	2.078	2.526	0.621	1.212	1.776	2.310	2.814
Area	0.479	0.933	1.362	1.767	2.148	0.528	1.031	1.510	1.964	2.393
I	0.356	0.660	0.917	1.132	1.311	0.477	0.890	1.246	1.549	1.807
S	0.285	0.528	0.733	0.906	1.049	0.347	0.647	0.906	1.127	1.314
r	0.862	0.841	0.820	0.800	0.781	0.950	0.929	0.908	0.888	0.869

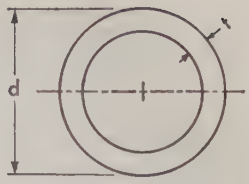
Diameter, d	3					3¼				
Thickness, t	1/8	3/16	1/4	5/16	3/8	1/8	3/16	1/4	5/16	3/8
Weight	1.328	1.949	2.540	3.103	3.637	1.443	2.122	2.771	3.392	3.983
Area	1.129	1.657	2.160	2.639	3.093	1.227	1.804	2.356	2.884	3.387
I	1.169	1.646	2.059	2.414	2.718	1.501	2.123	2.669	3.146	3.559
S	0.779	1.097	1.373	1.610	1.812	0.923	1.306	1.643	1.936	2.190
r	1.017	0.997	0.976	0.957	0.938	1.106	1.085	1.064	1.044	1.025

Diameter, d	3½					3¾				
Thickness, t	1/8	3/16	1/4	5/16	3/8	1/8	3/16	1/4	5/16	3/8
Weight	1.558	2.294	3.002	3.680	4.330	1.675	2.468	3.233	3.969	4.676
Area	1.325	1.951	2.553	3.129	3.682	1.424	2.099	2.749	3.375	3.976
I	1.890	2.685	3.390	4.013	4.559	2.341	3.339	4.231	5.026	5.732
S	1.080	1.534	1.937	2.293	2.605	1.249	1.781	2.256	2.681	3.057
r	1.194	1.173	1.153	1.132	1.113	1.282	1.261	1.241	1.220	1.201

Diameter, d	4					4¼				
Thickness, t	1/8	3/16	1/4	5/16	3/8	1/8	3/16	1/4	5/16	3/8
Weight	1.790	2.641	3.463	4.257	5.023	1.905	2.814	3.695	4.546	5.368
Area	1.522	2.246	2.945	3.620	4.271	1.620	2.393	3.142	3.866	4.565
I	2.859	4.090	5.200	6.198	7.090	3.449	4.948	6.308	7.539	8.649
S	1.429	2.045	2.600	3.098	3.544	1.623	2.328	2.968	3.548	4.070
r	1.371	1.350	1.329	1.308	1.289	1.459	1.438	1.417	1.397	1.376

TABLE 57 round tubes **Elements of Sections**

Continued



All dimensions in inches. I=Moment of Inertia in in.⁴
Weight in pounds per foot. S=Section Modulus in in.³
Area in square inches. r=Radius of Gyration in inches.

Diameter, d	4½					4¾				
Thickness, t	⅛	3/16	¼	5/16	⅜	⅛	3/16	¼	5/16	⅜
Weight	2.020	2.987	3.925	4.835	5.715	2.136	3.161	4.156	5.124	6.061
Area	1.718	2.540	3.338	4.111	4.860	1.816	2.688	3.534	4.357	5.154
I	4.114	5.917	7.563	9.062	10.42	4.860	7.006	8.975	10.78	12.42
S	1.829	2.630	3.362	4.028	4.633	2.047	2.950	3.779	4.538	5.231
r	1.547	1.526	1.505	1.485	1.464	1.636	1.615	1.594	1.573	1.553

Diameter, d	5					5¼				
Thickness, t	3/16	¼	5/16	⅜	7/16	3/16	¼	5/16	⅜	7/16
Weight	3.334	4.388	5.412	6.408	7.375	3.507	4.618	5.700	6.754	7.779
Area	2.835	3.731	4.602	5.449	6.271	2.982	3.927	4.847	5.743	6.615
I	8.220	10.55	12.70	14.67	16.47	9.568	12.30	14.83	17.16	19.31
S	3.288	4.220	5.078	5.866	6 587	3.645	4.687	5.650	6.538	7.356
r	1.703	1.682	1.661	1.641	1.621	1.791	1.770	1.749	1.729	1.709

Diameter, d	5½					6				
Thickness, t	3/16	¼	5/16	⅜	7/16	3/16	¼	5/16	⅜	½
Weight	3.680	4.849	5.989	7.101	8.183	4.027	5.311	6.567	7.793	10.16
Area	3.129	4.123	5.093	6.038	6.958	3.424	4.516	5.584	6.627	8.639
I	11.05	14.24	17.19	19.93	22.46	14.47	18.70	22.65	26.33	32.94
S	4.020	5.178	6.252	7.247	8.166	4.825	6.232	7.547	8.774	10.98
r	1.879	1.858	1.837	1.817	1.797	2.056	2.035	2.014	1.993	1.953

Diameter, d	6½					7				
Thickness, t	3/16	¼	5/16	⅜	½	3/16	¼	5/16	⅜	½
Weight	4.372	5.773	7.144	8.486	11.08	4.719	6.235	7.722	9.179	12.01
Area	3.718	4.909	6.075	7.216	9.425	4.013	5.302	6.566	7.805	10.21
I	18.54	24.01	29.15	33.97	42.71	23.30	30.23	36.78	42.96	54.24
S	5.703	7.385	8.966	10.45	13.14	6.656	8.638	10.51	12.27	15.50
r	2.233	2.212	2.190	2.170	2.129	2.410	2.388	2.367	2.346	2.305

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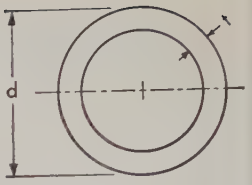
TABLE
57 Round Tubes — Elements of Sections

Concluded



All dimensions in inches.
Weight in pounds per foot.
Area in square inches.

I = Moment of Inertia in in.^{4}
S = Section Modulus in in.^{3}
r = Radius of Gyration in inches.

Diameter, d	7½					8				
Thickness, t	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Weight	5.065	6.696	8.298	9.871	12.94	5.412	7.158	8.875	10.56	13.85
Area	4.307	5.694	7.056	8.394	11.00	4.602	6.087	7.547	8.983	11.78
I	28.81	37.46	45.66	53.42	67.70	35.13	45.75	55.84	65.45	83.21
S	7.683	9.989	12.18	14.24	18.05	8.780	11.43	13.96	16.36	20.80
r	2.586	2.565	2.544	2.523	2.481	2.763	2.742	2.720	2.699	2.658

Diameter, d	8½					9				
Thickness, t	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Weight	5.758	7.620	9.453	11.26	14.78	6.105	8.081	10.03	11.95	15.70
Area	4.896	6.480	8.038	9.572	12.57	5.191	6.872	8.529	10.16	13.35
I	42.32	55.18	67.45	79.16	100.9	50.42	65.82	80.57	94.67	121.0
S	9.956	12.98	15.87	18.63	23.75	11.20	14.63	17.91	21.04	26.89
r	2.940	2.918	2.897	2.876	2.834	3.116	3.095	3.074	3.052	3.010

Diameter, d	9½					10				
Thickness, t	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Weight	6.450	8.544	10.61	12.64	16.63	6.797	9.006	11.18	13.34	17.55
Area	5.485	7.265	9.020	10.75	14.14	5.780	7.658	9.510	11.34	14.92
I	59.49	77.76	95.28	112.1	143.6	69.59	91.06	111.7	131.5	168.8
S	12.52	16.36	20.05	23.59	30.22	13.92	18.21	22.34	26.30	33.76
r	3.293	3.272	3.250	3.229	3.187	3.470	3.448	3.427	3.406	3.363

Diameter, d	10½					11				
Thickness, t	3/16	1/4	5/16	3/8	1/2	3/16	1/4	5/16	3/8	1/2
Weight	7.143	9.467	11.76	14.03	18.47	7.490	9.929	12.34	14.72	19.39
Area	6.074	8.050	10.00	11.93	15.71	6.369	8.443	10.49	12.52	16.49
I	80.78	105.8	129.9	153.1	196.8	93.10	122.0	149.9	176.9	227.8
S	15.39	20.15	24.74	29.15	37.49	16.93	22.19	27.26	32.16	41.42
r	3.647	3.625	3.604	3.582	3.540	3.823	3.802	3.780	3.759	3.717

TABLE

58 pipe Elements of Sections

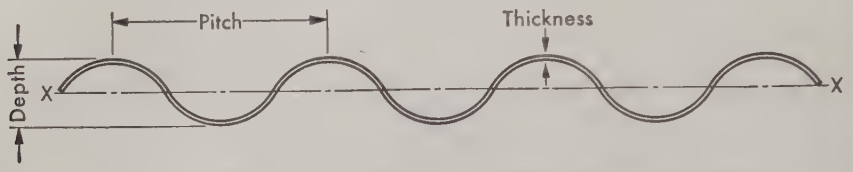
Nominal Pipe Size, In.	Schedule Number ①	Outside Diameter, In.	Inside Diameter, In.	Wall Thickness, In.	Weight per Linear Foot, Pounds	Cross-Sectional Wall Area, Sq In.	Moment of Inertia, In.⁴	Section Modulus, In.³	Radius of Gyration, In.
⅛	40②	0.405	0.269	0.068	0.085	0.0720	0.0011	0.0053	0.1215
	80③	0.405	0.215	0.095	0.109	0.0925	0.0012	0.0060	0.1146
¼	40②	0.540	0.364	0.088	0.147	0.1250	0.0033	0.0123	0.1628
	80③	0.540	0.302	0.119	0.185	0.1574	0.0038	0.0139	0.1547
⅜	40②	0.675	0.493	0.091	0.196	0.1670	0.0073	0.0216	0.2090
	80③	0.675	0.423	0.126	0.256	0.2173	0.0086	0.0255	0.1992
½	40②	0.840	0.622	0.109	0.294	0.2503	0.0171	0.0407	0.2613
	80③	0.840	0.546	0.147	0.376	0.3200	0.0201	0.0478	0.2505
¾	40②	1.050	0.824	0.113	0.391	0.3326	0.0370	0.0705	0.3337
	80③	1.050	0.742	0.154	0.510	0.4335	0.0448	0.0853	0.3214
1	40②	1.315	1.049	0.133	0.581	0.4939	0.0873	0.1328	0.4205
	80③	1.315	0.957	0.179	0.751	0.6388	0.1056	0.1606	0.4066
1¼	40②	1.660	1.380	0.140	0.786	0.6685	0.1947	0.2346	0.5397
	80③	1.660	1.278	0.191	1.037	0.8815	0.2418	0.2913	0.5238
1½	40②	1.900	1.610	0.145	0.940	0.7995	0.3099	0.3262	0.6226
	80③	1.900	1.500	0.200	1.256	1.0681	0.3912	0.4118	0.6052
2	40②	2.375	2.067	0.154	1.264	1.0745	0.6657	0.5606	0.7871
	80③	2.375	1.939	0.218	1.737	1.4773	0.8679	0.7309	0.7665
2½	40②	2.875	2.469	0.203	2.004	1.7041	1.530	1.064	0.9474
	80③	2.875	2.323	0.276	2.650	2.2535	1.924	1.339	0.9241
3	40②	3.500	3.068	0.216	2.621	2.2285	3.017	1.724	1.164
	80③	3.500	2.900	0.300	3.547	3.0159	3.894	2.225	1.136
3½	40②	4.000	3.548	0.226	3.151	2.6795	4.788	2.394	1.337
	80③	4.000	3.364	0.318	4.326	3.6784	6.281	3.140	1.307
4	40②	4.500	4.026	0.237	3.733	3.1740	7.232	3.214	1.510
	80③	4.500	3.826	0.337	5.183	4.4074	9.611	4.272	1.477
5	40②	5.563	5.047	0.258	5.057	4.2999	15.16	5.451	1.878
	80③	5.563	4.813	0.375	7.188	6.1120	20.67	7.432	1.839
6	40②	6.625	6.065	0.280	6.564	5.5814	28.14	8.496	2.246
	80③	6.625	5.761	0.432	9.884	8.4050	40.49	12.22	2.195
8	30	8.625	8.071	0.277	8.543	7.2646	63.35	14.69	2.953
	40	8.625	7.981	0.322	9.878	8.3992	72.49	16.81	2.938
	80	8.625	7.625	0.500	15.01	12.7628	105.7	24.51	2.878
10		10.750	10.192	0.279	10.79	9.1779	125.8	23.41	3.704
	30	10.750	10.136	0.307	11.84	10.0720	137.4	25.57	3.694
	40	10.750	10.020	0.365	14.00	11.9082	160.7	29.90	3.674
	60	10.750	9.750	0.500	18.93	16.1007	211.9	39.43	3.628
12		12.750	12.000	0.375	17.14	14.5789	279.3	43.81	4.377
		12.750	11.750	0.500	22.63	19.2423	361.5	56.71	4.335

①Schedule Numbers conform to American Standard for Wrought Iron and Wrought Steel Pipe, ASA B36.10.
②Also designated as Standard Pipe.
③Also designated as Extra-Heavy or Extra-Strong Pipe.

TABLE
59 corrugated sheet[1] Elements of Sections

Dimensions in inches
Weight in lb per sq ft
Area in sq in. per ft of width

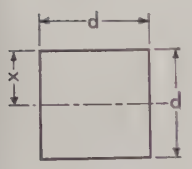
Moment of Inertia, I, in in.^{4} per ft of width
Section Modulus, S, in in.^{3} per ft of width
Radius of Gyration, r, in inches



Thickness	Weight[2]	Area	I_{x-x}	S_{x-x}	r_{x-x}
Alcoa Industrial Roofing and Siding Sheet (Pitch=2.67 in., Depth=7/8 in.)					
0.024	0.414	0.352	0.0307	0.0708	0.295
0.032	0.552	0.469	0.0409	0.0936	0.295
2½ x ½ Alcoa Farm Roofing Sheet (Pitch=2.67 in., Depth=½ in.)					
0.019	0.289	0.246	0.0069	0.0274	0.167
0.024	0.365	0.310	0.0085	0.0339	0.165
1¼ x ¼ Alcoa Farm Roofing Sheet (Pitch=1.26 in., Depth=¼ in.)					
0.019	0.289	0.246	0.0016	0.0126	0.080

[1] A variety of special types and sizes of corrugation and other thicknesses of sheet can be furnished.
[2] Weight given is for 3004 alloy. Corrugated sheet can be furnished in other alloys. Allowance for overlaps not included in weight.

Square



$$A = d^2$$

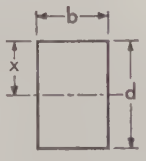
$$x = \frac{d}{2}$$

$$I = \frac{d^4}{12}$$

$$S = \frac{d^3}{6}$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

Rectangle



$$A = bd$$

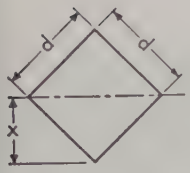
$$x = \frac{d}{2}$$

$$I = \frac{bd^3}{12}$$

$$S = \frac{bd^2}{6}$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

Square



$$A = d^2$$

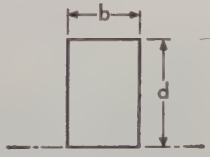
$$x = \frac{d}{\sqrt{2}} = 0.7071d$$

$$I = \frac{d^4}{12}$$

$$S = \frac{\sqrt{2}\,d^3}{12} = 0.1179d^3$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

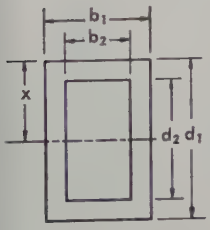
Rectangle



$$A = bd$$

$$I = \frac{bd^3}{3}$$

Hollow Rectangle



$$A = b_1d_1 - b_2d_2$$

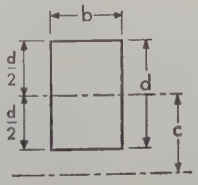
$$x = \frac{d_1}{2}$$

$$I = \frac{b_1d_1^3 - b_2d_2^3}{12}$$

$$S = \frac{b_1d_1^3 - b_2d_2^3}{6d_1}$$

$$r = \sqrt{\frac{I}{A}}$$

Rectangle



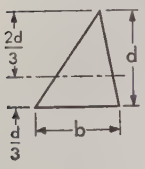
$$A = bd$$

$$I = A\left(\frac{d^2}{12} + c^2\right)$$

Continued on next page

Continued

Triangle

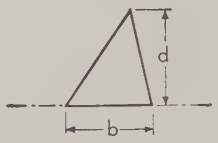


$$A=\frac{bd}{2}$$

$$I=\frac{bd^3}{36}$$

$$r=\frac{d}{\sqrt{18}}=0.2357d$$

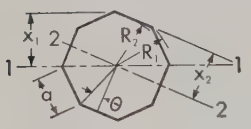
Triangle



$$A=\frac{bd}{2}$$

$$I=\frac{bd^3}{12}$$

Regular Polygon



n = Number of Sides

$$a=2\sqrt{R_1^2-R_2^2}\ ,\Theta=\frac{180^\circ}{n}$$

$$A=\frac{na^2\cot\Theta}{4}=\frac{nR_1^2\sin 2\Theta}{2}=nR_2^2\tan\Theta$$

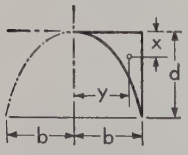
$$x_1=R_1=\frac{a}{2\sin\Theta},\ x_2=R_2=\frac{a}{2\tan\Theta}$$

$$I_{1\text{-}1}=I_{2\text{-}2}=\frac{A\,(6R_1^2-a^2)}{24}=\frac{A\,(12R_2^2+a^2)}{48}$$

$$S_{1\text{-}1}=\frac{A\,(6R_1^2-a^2)}{24R_1},\ S_{2\text{-}2}=\frac{A\,(12R_2^2+a^2)}{48R_2}$$

$$r_{1\text{-}1}=\sqrt{\frac{6R_1^2-a^2}{24}},\ r_{2\text{-}2}=\sqrt{\frac{12R_2^2+a^2}{48}}$$

Complement of Half Parabola

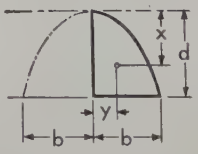


$$A=\frac{bd}{3}$$

$$x=\frac{3d}{10}$$

$$y=\frac{3b}{4}$$

Half Parabola

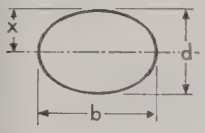


$$A=\frac{2\,bd}{3}$$

$$x=\frac{6d}{10}$$

$$y=\frac{3b}{8}$$

Ellipse



$$A=\frac{\pi\, bd}{4}$$

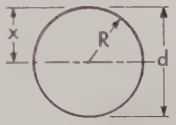
$$x=\frac{d}{2}$$

$$I=\frac{\pi\, bd^3}{64}$$

$$S=\frac{\pi\, bd^2}{32}$$

$$r=\frac{d}{4}$$

Circle



$$A=\pi\, R^2=\frac{\pi d^2}{4}$$

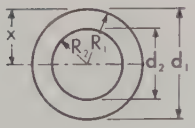
$$x=R=\frac{d}{2}$$

$$I=\frac{\pi R^4}{4}=\frac{\pi d^4}{64}$$

$$S=\frac{\pi R^3}{4}=\frac{\pi d^3}{32}$$

$$r=\frac{R}{2}=\frac{d}{4}$$

Hollow Circle



$$A=\pi\,(R_1^2-R_2^2)=\frac{\pi(d_1^2-d_2^2)}{4}$$

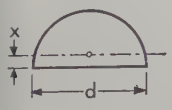
$$x=R_1=\frac{d_1}{2}$$

$$I=\frac{\pi(R_1^4-R_2^4)}{4}=\frac{\pi(d_1^4-d_2^4)}{64}$$

$$S=\frac{\pi(R_1^4-R_2^4)}{4R_1}=\frac{\pi(d_1^4-d_2^4)}{32d_1}$$

$$r=\sqrt{\frac{R_1^2+R_2^2}{4}}=\sqrt{\frac{d_1^2+d_2^2}{16}}$$

Half Circle

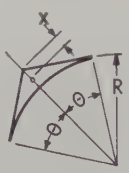


$$A=\frac{\pi R^2}{2}=\frac{\pi d^2}{8}$$

$$I=0.1098R^4=0.0069d^4$$

$$x=\frac{4R}{3\pi}=\frac{2d}{3\pi}$$

Circular Fillet



$$A=(\tan\Theta-\Theta)R^2$$

$$x=\left(\sec\Theta-\frac{\tan^2\Theta\sin\Theta}{3(\tan\Theta-\Theta)}\right)R$$

(Θ is expressed in radians)

TOLERANCES AND COMMERCIAL SIZES OF ALUMINUM ALLOY PRODUCTS

The Tolerance tables that follow in this section do not indicate availability. For availability, see tables on Commercial Sizes.

TABLE 61

sheet[9] and plate[9]

THICKNESS—Standard Tolerances[1][4]

Alloys: 2014, Alclad 2014, 2024[43], Alclad 2024[43], 3004, Alclad 3004, 5052, 5083, 5086, 5154, 5254, 5454, 5456, 5652, 6061, Alclad 6061, 7075 and Alclad 7075, 7178, Alclad 7178 and Brazing Sheet Nos. 11, 12, 21, 22

Specified Thickness, Inches	Allowable Deviation from Specified Thickness, Inch, Plus or Minus											
	Width, Inches											
	18 and less	Over 18 through 36	Over 36 through 48	Over 48 through 54	Over 54 through 60	Over 60 through 66	Over 66 through 72	Over 72 through 78	Over 78 through 84	Over 84 through 90	Over 90 through 96	Over 96 through 144
0.006 to 0.010	0.001	0.0015	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.011 to 0.017	0.0015	0.0015	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.018 to 0.028	0.0015	0.002	0.0025	0.0035	0.004	.....	.....	.....	.....	.....	.....	.....
0.029 to 0.036	0.002	0.002	0.0025	0.004	0.005	.....	.....	.....	.....	.....	.....	.....
0.037 to 0.045	0.002	0.0025	0.003	0.004	0.005	0.005	0.005	0.006	0.006	.....	.....	.....
0.046 to 0.068	0.0025	0.003	0.004	0.005	0.006	0.006	0 006	0.007	0 007	.....	.....	.....
0.069 to 0.076	0.003	0.003	0.004	0.005	0.006	0.006	0.006	0.007	0.007	0.012	.....	.....
0.077 to 0.096	0.0035	0.0035	0.004	0.005	0.006	0.006	0 006	0.007	0.007	0.012	.....	.....
0.097 to 0.108	0.004	0.004	0.005	0.005	0.007	0 007	0 007	0.008	0.008	0.016	0.018	0.020
0.109 to 0.125	0.0045	0.0045	0.005	0.005	0.007	0.007	0.007	0.008	0.008	0.016	0.018	0.020
0.126 to 0.140	0.0045	0.0045	0.005	0 005	0.007	0.010	0.012	0.013	0.014	0.016	0.018	0.020
0.141 to 0.172	0.006	0.006	0.008	0.008	0.009	0.012	0.014	0.015	0.016	0.017	0.019	0.023
0.173 to 0.203	0.007	0.007	0.010	0.010	0.011	0.014	0.016	0.017	0.017	0.017	0.022	0.026
0.204 to 0.249	0.009	0.009	0.011	0.011	0.013	0.016	0.018	0.018	0.018	0.018	0.024	0.028
0.250 to 0.320	0.013	0.013	0.013	0.013	0.015	0.018	0.020	0.020	0.020	0.020	0.025	0.030
0.321 to 0.438	0.019	0.019	0.019	0.019	0.020	0.020	0.023	0.023	0.025	0.025	0.026	0.033
0.439 to 0.625	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.035	0.035
0.626 to 0.875	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.037	0.037	0.037	0.045	0.045
0.876 to 1.125	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.045	0.045	0.045	0.055	0.055
1.126 to 1.375	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.052	0.052	0.052	0.065	0.065
1.376 to 1.625	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.060	0.060	0.060	0.075	0.075
1.626 to 1.875	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.070	0.070	0.070	0.088	0.088
1.876 to 2.250	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.080	0.080	0.080	0.100	0.100
2.251 to 2.750	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.100	0.100	0.100	0.125	0.125
2.751 to 3.000	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.120	0.120	0.120	0.150	0 150

See page 296 for footnotes.

TABLE 62

sheet[2] and plate[3]

FLAT LAB COILS

THICKNESS—Standard Tolerances①④

Alloys: EC, 1060, 1100, 3003, Alclad 3003, 5005, 5050, 5357, Reflector Sheet Nos. 12, 13, 22, 23

Specified Thickness, Inches	Allowable Deviation from Specified Thickness, Inch, Plus or Minus							
	Width, Inches							
	18 and less	Over 18 through 36	Over 36 through 54	Over 54 through 72	Over 72 through 90	Over 90 through 102	Over 102 through 132	Over 132 through 144
0.006 to 0.007	0.001	0.001	.....	.....	.....	.....	.....	....
0.008 to 0.010	0.001	0.0015	.....	.....	.....	.....	.....	.....
0.011 to 0.017	0.0015	0.0015	0.002	.....	.....	.....	.....	.....
0.018 to 0.028	0.0015	0.002	0.0025	.....	.....	.....	.....	.....
0.029 to 0.036	0.002	0.002	0.0025	0.0035	0.005	.....	....	.....
0.037 to 0.045	0.002	0.0025	0.003	0.004	0.005	.....	....	.....
0.046 to 0.068	0.0025	0.003	0.004	0.005	0.006	.....	.....	.....
0.069 to 0.076	0.0025	0.003	0.004	0.006	0.008	.....	.....	.....
0.077 to 0.096	0.003	0.003	0.004	0.006	0.008	.....	.....	.....
0.097 to 0.108	0.0035	0.004	0.005	0.007	0.009	0.010	....	.....
0.109 to 0.140	0.0045	0.0045	0.005	0.007	0.009	0.010	.....	.....
0.141 to 0.172	0.006	0.006	0.008	0.009	0.011	0.012	0.015	.....
0.173 to 0.203	0.007	0.007	0.009	0.011	0.013	0.015	0.018	.....
0.204 to 0.249	0.009	0.009	0.011	0.013	0.015	0.017	0.020	.....
0.250 to 0.320	0.013	0.013	0.013	0.015	0.017	0.020	0.023	0.032
0.321 to 0.438	0.019	0.019	0.019	0.019	0.023	0.026	0.026	0.035
0.439 to 0.625	0.025	0.025	0.025	0.025	0.030	0.035	0.035	0.040
0.626 to 0.875	0.030	0.030	0.030	0.030	0.037	0.045	0.045	0.050
0.876 to 1.125	0.035	0.035	0.035	0.035	0.045	0.055	0.055	0.060
1.126 to 1.375	0.040	0.040	0.040	0.040	0.052	0.065	0.065	0.070
1.376 to 1.625	0.045	0.045	0.045	0.045	0.060	0.075	0.075	0.080
1.626 to 1.875	0.052	0.052	0.052	0.052	0.070	0.088	0.088	0.095
1.876 to 2.250	0.060	0.060	0.060	0.060	0.080	0.100	0.100	0.105
2.251 to 2.750	0.075	0.075	0.075	0.075	0.100	0.125	0.125	0.130
2.751 to 3.000	0.090	0.090	0.090	0.090	0.120	0.150	0.150	0.150

See page 296 for footnotes.

TABLE 63

sheet[2]

WIDTH and LENGTH

Standard Tolerances[1][4]

Thickness, Inch	Allowable Deviation from Specified Width, Inch, Plus or Minus					
	Width, Inches					
	Up through 4	Over 4 through 18	Over 18 through 36	Over 36 through 54	Over 54 through 72	Over 72 through 132
0.006 to 0.064	1/32	1/16	3/32	1/8	5/32	3/16
0.065 to 0.102	1/16	1/16	3/32	1/8	5/32	3/16
0.103 to 0.249	1/8	3/32[5]	1/8	3/16	3/16	1/4

Thickness, Inch	Allowable Deviation from Specified Length, Inch, Plus or Minus				
	Length, Inches				
	18 and less	Over 18 through 48	Over 48 through 120	Over 120 through 180	Over 180 through 540
0.006 to 0.249	1/16	3/32	1/8	5/32	1/4

See page 296 for footnotes.

TABLE 64

plate[2]

WIDTH and LENGTH

Standard Tolerances[1][4]

Thickness, Inch	Allowable Deviation from Specified Width or Length, Inch, Plus Only			
	Specified Width or Length, Inches			
	144 and less	Over 144 through 240	Over 240 through 540	Over 540 through 720
0.250 to 0.500	3/8	7/16	1/2	5/8
0.501 to 1.000	1/2	9/16	5/8	3/4
1.001 to 1.250	5/8	3/4	1	1 1/4

See page 296 for footnotes.

TABLE 65

plate[4]

WIDTH and LENGTH
Standard Tolerances[1][4]

Specified Thickness, Inches	Specified Width or Length, Inches			
	Tolerance, Inches Plus or Minus			
	Up thru 10	Over 10 thru 48	Over 48 thru 84	Over 84
0.250–3.000	3/32	3/16	1/4	5/16

See page 296 for footnotes.

TABLE 66

sheet[2]

WIDTH
Standard Tolerances[1][4]

Specified Thickness, Inches	Specified Width, Inches				
	Tolerance, Inches Plus or Minus				
	Up thru 6	Over 6 thru 12	Over 12 thru 24	Over 24 thru 48	Over 48 thru 60
0.006–0.125	0.010	0.016	1/32	3/64	1/16

See page 296 for footnotes.

TABLE 67

sheet[2] and plate[3]

SQUARENESS
Standard Tolerances[1][4]

Specified Thickness, Inches	Allowable Difference in Length of Diagonals, Inches						
	Specified Length, Inches						
	Up thru 18	Over 18 thru 48	Over 48 thru 120	Over 120 thru 144	Over 144 thru 180	Over 180 thru 240	Over 240 thru 540
0.006–0.249	1/8	3/16	1/4	5/16	5/16	1/2	1/2
0.250–0.500	3/8	3/8	3/8	3/8	7/16	9/16	5/8
0.501–1.000	1/2	1/2	1/2	1/2	9/16	5/8	3/4
1.001–3.000	5/8	5/8	5/8	5/8	3/4	3/4	1

See page 296 for footnotes.

TABLE 68

sheet[5] and plate[5]

LATERAL BOW (camber)[6]

Standard Tolerances[1][4]

Length, Feet	Allowable Lateral Bow, Inch in 10 Feet		
	Flat Sheet and Plate		Coiled Sheet
	Widths 4 Inches and Less	Widths over 4 Inches	All Widths
12 and less	1	1/8	1
Over 12	[7]	[7]	1

See page 296 for footnotes.

TABLE 69

sheet[5] and plate[5]

CIRCLES (SHEARED OR BLANKED)

DIAMETER

Standard Tolerances[1][4]

Thickness, Inch	Allowable Deviation from Specified Diameter, Inch, Plus or Minus			
	Diameter, Inches			
	Up through 18	Over 18 through 36	Over 36 through 96	Over 96 through 132
0.006 to 0.249	1/32	3/64	1/16	1/8
0.250 to 0.375	....	1/16	1/8	3/16
0.376 to 0.625	....	1/8	3/16	1/4
0.626 to 0.875	....	3/16	1/4	3/8
0.876 to 1.250	....	1/4	3/8	1/2

See page 296 for footnotes.

TABLE 70

sheet[5] and plate[5]

CIRCLES (SAWED)

DIAMETER

Standard Tolerances[1][4]

Thickness, Inches	Allowable Deviation from Specified Diameter, Inch, Plus or Minus		
	Diameter, Inches		
	Up through 18	Over 18 through 60	Over 60 through 132
0.081 to 1.000	1/8	3/16	1/4
1.001 to 3.000	1/4	3/8	1/2

See page 296 for footnotes.

TABLE 71

wire and rod

DIAMETER

Standard Tolerances

Specified Diameter, Inches	Allowable Deviation from Specified Diameter, Inch, Plus or Minus, Except as Noted			
	Drawn Wire	Cold-finished Rod	Rolled Rod	
			Plus	Minus
Under 0.036	0.0005	.....	.....	.....
0.036 to 0.064	0.001	.....	.....	.....
0.065 to 0.374	0.0015	.....	.....	.....
0.375 to 0.500	.....	0.0015	.....	.....
0.501 to 1.000	.....	0.002	.....	.....
1.001 to 1.500	.....	0.0025	.....	.....
1.501 to 2.000	.....	0.004	0.006	0.006
2.001 to 3.000	.....	0.006	0.008	0.008
3.001 to 3.499	.....	.....	0.012	0.012
3.500 to 5.000	.....	.....	0.031	0.016
5.001 to 8.000	.....	.....	0.062	0.031

TABLE 72

wire and bar

DISTANCE ACROSS FLATS

Standard Tolerances

Specified Distance Across Flats, Inches	Allowable Deviation from Specified Distance Across Flats, Inch, Plus or Minus		
	Drawn Wire	Cold-finished Bar	Rolled Bar(45)
Under 0.036	0.001	.....	.....
0.036 to 0.064	0.0015	.....	.....
0.065 to 0.374	0.002	.....	.....
0.375 to 0.500	.....	0.002	.....
0.501 to 1.000	.....	0.0025	.....
1.001 to 1.500	.....	0.003	.....
1.501 to 2.000	.....	0.005	0.016
2.001 to 3.000	.....	0.008(44)	0.020
3.001 to 4.000	.....	.....	0.020

See page 296 for footnotes.

TABLE 73

wire and bar

THICKNESS and WIDTH

Standard Tolerances

Specified Thickness or Width, Inches	Allowable Deviation from Specified Thickness or Width, Inch, Plus or Minus			
	Drawn (8) Wire and Cold-finished Bar (9)		Rolled Bar (9)	
	Thickness	Width	Thickness	Width (47)
Under 0.036	0.001	.....	.....	.....
0.036 to 0.064	0.0015	.....	.....	.....
0.065 to 0.500	0.002	0.002	0.006 (10)	.....
0.501 to 0.750	0.0025	0.0025	0.008	.016
0.751 to 1.000	0.0025	0.0025	0.012	.016
1.001 to 1.500	0.003	0.003	0.016	.016
1.501 to 2.000	.....	0.005	0.016	.031
2.001 to 4.000	.....	0.005	0.020	.031
4.001 to 6.000	.....	.....	.....	.047
6.001 to 10.000	.....	.....	.....	.062

See page 296 for footnotes.

TABLE 74

bar (rough rolled)

THICKNESS and WIDTH

Standard Tolerances

Size			Allowable Deviation from Specified Thickness or Width, Inch, Plus or Minus	
Thickness, Inches		Width, Inches	Thickness	Width
2.000–8.000	by	4.000–16.000	1/16	1/4

TABLE 75 rod and bar

STRAIGHTNESS[11][12]

Standard Tolerances

	Allowable Deviation from Straight, Inch	
	Lengths 5 Feet and Less	Lengths over 5 Feet
Cold-finished Material	0.125	Length (ft) x 0.025
Rolled Material	0.250	Length (ft) x 0.050

See page 296 for footnotes.

TABLE 76 bar

ANGULARITY

Standard Tolerances

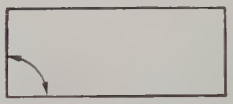
Minimum Specified Thickness, Inches	 Allowable Deviation from Specified Angles
All	±1°

TABLE 77 bar

CONFORMANCE OF FLAT SURFACES—RECTANGLES[40]

Standard Tolerances

Allowable deviation from flat, 0.004 inch per inch of width, 0.004 inch minimum.

See page 296 for footnotes.

TABLE 78

bar

TWIST

Standard Tolerances

Circumscribed Circle Diameter, ⑬ Inches	Allowable Deviation from Straight, ⑭ Degrees	
	In Each Foot of Length ⑮	In Total Length of Piece
1.499 and less	1½	Length (ft) x 1
1.500 to 2.999	1	Length (ft) x ½ (not over 5)
3.000 and over	½	Length (ft) x ¼ (not over 3)

See page 296 for footnotes.

TABLE 79

rod and bar

SPECIFIC and MULTIPLE LENGTHS⑯

Standard Tolerances

Specified Outside Dimension Width or Depth (Whichever Greatest), Inches	Tolerance, Inch, Plus			
	Allowable Deviation from Specified Length, Inches			
	Specified Length, Feet			
	Up Through 12	Over 12 Through 30	Over 30 Through 50	Over 50
Under 3.000	⅛	¼	⅜	1
3.000–7.999	3/16	5/16	7/16	1
8.000 and over	¼	⅜	½	1

See page 296 for footnotes.

TABLE 80

wire

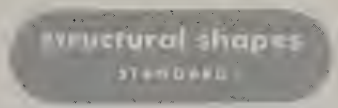
FLATTENED

THICKNESS and WIDTH

Standard Tolerances

Dimensions	Commercial Sizes, Inches		Allowable Deviation, Inch, Plus or Minus
	Mimimum	Maximum	
Thicknesses	0.021	0.060	0.0015
	0.061	0.187	0.002
Widths	0.063	0.875	0.007
	0.876	2.000	0.010

TABLE 81



DIMENSIONS and WEIGHT

Standard Tolerances

	Section	Tolerance
Thickness[17]	Channels up to 15″ I-Beams up to 12″ Angles up to 8″ x 8″ Zees up to 6″	±2.5 per cent of the nominal thickness, except that no tolerance shall be less than ±0.010 inch.
Over-all dimensions	Channels up to 15″ I-Beams up to 12″	Width of flange: ±4 per cent of nominal width.
	Angles up to 8″ x 8″ Zees up to 6″	Length of leg: ±2.5 per cent of nominal length, except that no tolerance shall be less than ±1/16 inch.
Weight[17]	Channels from 3″ up to 15″ I-Beams up to 12″ Angles from 3″ x 3″ up to 8″ x 8″ Zees from 3″ up to 6″	Average weight per foot of an order item should not vary more than ±2.5 per cent from the nominal weight per foot.

Length[18]	Sizes—Specified width or depth, whichever greater, inches	Up thru 12	Over 12–30	Over 30–50	Over 50
	Under 3.000	1/8	1/4	3/8	1
	3.000–7.999	3/16	5/16	7/16	1
	8.000 and over	1/4	3/8	1/2	1

Depth	Channels	+ 3/32 − 1/16 inch
Straightness	All sections	Lengths up thru 5 ft, allowable deviation 1/8″. Lengths over 5 ft, allowable deviation length in ft x 0.025.
Flat surfaces	All sections	Allowable deviation from flat, 0.004 inch per inch of width; 0.004 inch minimum.
Angularity	Minimum specified leg thickness, inches	Allowable deviation from 90 degrees
	Under 0.188	±2°
	0.188 to 0.749	±1½°
	0.750 and over	±1°

Twist	Specified width or depth, whichever greater, inches	Allowable deviation from straight, degrees: In each foot of length	In total length of piece
	1.499 and less	1°	Length (ft) x 1°
	1.500 to 2.999	½°	Length (ft) x ½° (not over 5°)
	3.000 and over	¼°	Length (ft) x ¼° (not over 3°)

See page 206 for footnotes

TABLE **82**

rod, bar, shapes (extruded)

CROSS-SECTIONAL DIMENSIONS

Standard Tolerances[24]

Specified Dimension, Inches	Tolerance 1 19, Inch											
	Metal Dimensions				Space Dimensions							
	Allowable Deviation from Specified Dimension Where 75% or More of the Dimension Is Metal Inch, Plus or Minus				Allowable Deviation from Specified Dimension Where More Than 25% of the Dimension Is Space 20 21 Inch, Plus or Minus							
					At Dimensioned Points (Distance from Base of Leg)							
	All Excepting Those Covered by Column 3		Wall Thickness 22 31 Completely Enclosing Space 0.11 sq in. and Over (Eccentricity)		0.250–0.624 Inch		0.625–1.249 Inches		1.250–2.499 Inches		2.500 Inches or More	
Col. 1	Col. 2		Col. 3 23		Col. 4		Col. 5		Col. 6		Col. 7	
	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys
Under 0.125	.009	.006			.015	.010	.018	.012	.021	.014	.024	.016
0.125 to 0.249	.011	.007			.018	.012	.021	.014	.024	.016	030	.020
0.250 to 0.499	.012	.008			.021	.014	.024	.016	.027	.018	.033	.022
0.500 to 0.749	.014	.009	Plus	Plus	.024	.016	.027	.018	.030	.020	.039	.026
0.750 to 0.999	.015	.010	or	or	.027	.018	.030	.020	.033	.022	.045	.030
1.000 to 1.499	.018	.012	minus	minus	.030	.020	.033	.022	.039	.026	.051	.034
1.500 to 1.999	.024	.016	15%	10%	.036	.024	.042	.028	.051	.034	.075	.050
2.000 to 3.999	.036	.024	±0.090	±0.060	.048	.032	.054	.036	.072	.048	.096	064
4.000 to 5.999	.051	.034	max.	max.	.063	.042	.075	.050	.096	.064	.132	.088
6.000 to 7.999	.066	.044	±0.015	±0.010	.081	.054	.093	.062	.123	.082	.168	.112
8.000 to 9.999	.081	.054	min.	min.	.096	.064	.111	.074	.150	.100	.204	.136
10.000 to 11.999	.096	.064			.111	.074	.132	.088	.174	.116	.240	.160
12.000 to 13.999	.111	.074			.126	.084	.150	.100	.201	.134	.276	.184
14.000 to 15.000	.120	.080			.135	.090	.159	.106	.213	.142	.294	.196

See pages 296 and 297 for footnotes.

TABLE 83 — rod, bar, shapes (extruded)

ANGULARITY

Standard Tolerances[24]

Minimum Specified Leg Thickness, Inches	Tolerance, Degrees, Plus or Minus — Allowable Deviation from Specified Angle
Under 0.188	2°
0.188–0.749	1½°
0.750 and over and all solid sections	1°

See page 297 for footnotes.

TABLE 84 — rod, bar, shapes (extruded)

FLAT and CURVED SURFACES

Standard Tolerances[24]

FLAT SURFACES

Allowable deviation from flat, 0.004 inch per inch of width; 0.004 inch minimum. Not applicable to surfaces of walls 0.187 inch or less in thickness which completely enclose a void.

CURVED SURFACES

Allowable deviation from specified contour is 0.005 inch per inch of chord length; 0.005 inch minimum; not applicable to more than 90 degrees of any arc.

See page 297 for footnotes.

TABLE 85 — rod, bar, shapes (extruded)

CORNER and FILLET RADII

Standard Tolerances[24]

Specified Radius, Inches	Allowable Deviation from Specified Radius
Sharp corners	+1/64 inch
Under 0.188	±1/64 inch
0.188 and over	±10%

See page 297 for footnotes.

TABLE 86

rod, bar, shapes (extruded)

TWIST

Standard Tolerances[24]

Circumscribing Circle Diameter[13] (Shapes); Specified Width (Bar), Inches	Allowable Deviation from Straight,[14] Degrees	
	In Each Foot of Length	In Total Length of Piece
Under 1.500	1	Length (ft) x 1
1.500–2.999	½	Length (ft) x ½ (not over 5)
3.000 and over	¼	Length (ft) x ¼ (not over 3)

See pages 296 and 297 for footnotes.

TABLE 87

rod, bar, shapes (extruded)

STRAIGHTNESS

Standard Tolerances[24]

Circumscribing Circle Diameter[13] (Shapes); Specified Diameter (Rod); Specified Width (Bar), Inches	Minimum Thickness, Inch	Allowable Deviation from Straight, Inch[14][25]	
		In Each Foot of Length	In Total Length of Piece
Under 1.500	Under 0.095	.050	Length (ft) x .050
Under 1.500	0.095 and over	.0125	Length (ft) x .0125
1.500 and over	.....	.0125	Length (ft) x .0125

See pages 296 and 297 for footnotes.

TABLE 88

rod, bar, shapes (extruded)

LENGTH

Standard Tolerances[24]

Circumscribing Circle Diameter (Shapes); Specified Diameter (Rod); Specified Width (Bar), Inches	Tolerance, Inches, Plus			
	Allowable Deviation from Specified Length[18][26]			
	Specified Length, Feet			
	Up Through 12	Over 12 Through 30	Over 30 Through 50	Over 50
Under 3.000	⅛	¼	⅜	1
3.000–7.999	3/16	5/16	7/16	1
8.000 and over	¼	⅜	½	1

See pages 296 and 297 for footnotes.

TABLE 89

Tube (extruded) ROUND

DIAMETER

Standard Tolerances

Specified Outside or Inside Diameter, Inches	Allowable Deviation from Specified Diameter,①㉗ Inch, Plus or Minus			
	Mean Diameter㉘		Diameter at any Point㉘	
	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys
0.500– 0.999	.015	.010	.030	.020
1.000– 1.999	.018	.012	.038	.025
2.000– 3.999	.023	.015	.045	.030
4.000– 5.999	.038	.025	.075	.050
6.000– 7.999	.053	.035	.113	.075
8.000– 9.999	.068	.045	.150	.100
10.000–11.999	.083	.055	.188	.125
12.000–12.875	.098	.065	.225	.150

See pages 296 and 297 for footnotes.

TABLE 90

Tube (extruded) SQUARE—RECTANGULAR HEXAGONAL—OCTAGONAL

WIDTH and DEPTH

Standard Tolerances

Specified Width or Depth, Inches	Allowable Deviation of Width or Depth from Specified Width or Depth,①㉗ Inch, Plus or Minus				
	At Corners		Not at Corners㉘		
			Square, Hexagonal, Octagonal		Rectangular
Col. 1	Col. 2		Col. 3		Col. 4
	5083, 5086, 5456	Other Alloys	5083, 5086, 5456	Other Alloys	
0.500–0.749	.018	.012	.030	.020	The tolerance for the width is
0.750–0.999	.021	.014	.030	.020	the value in column 3 for a
1.000–1.999	.027	.018	.038	.025	dimension equal to the depth,
2.000–3.999	.038	.025	.053	.035	and conversely, but in no case
4.000–4.999	.053	.035	.068	.045	is the tolerance less than at
5.000–5.999	.068	.045	.083	.055	the corner.㉚

See pages 296 and 297 for footnotes.

TABLE 91

Tube (extruded)

WALL THICKNESS

Standard Tolerances

ROUND

Specified Thickness,㉛ Inches	Tolerance,①㉗ Inch, Plus or Minus								
	Allowable Deviation of **Mean** Wall Thickness㉜ from Specified Wall Thickness								Allowable Deviation of Wall Thickness **at Any Point** from Mean Wall Thickness,㉜ (Eccentricity)
	Outside Diameter, Inches								
	Under 1.250		1.250–2.999		3.000–4.999		5.000 and Over		
	5083 5086 5456	Other Alloys	5083 5086 5456	Other Alloys	5083 5086 5456	Other Alloys	5083 5086 5456	Other Alloys	All Alloys
Under 0.047	.009	.006	....	....	....	....	....	....	
0.047–0.061	.011	.007	.012	.008	.012	.008	.015	.010	
0.062–0.077	.012	.008	.012	.008	.014	.009	.018	.012	
0.078–0.124	.014	.009	.014	.009	.015	.010	.023	.015	Plus and minus 10% of mean wall thickness max. ±0.060 min. ±0.010
0.125–0.249	.014	.009	.014	.009	.020	.013	.030	.020	
0.250–0.374	.017	.011	.017	.011	.024	.016	.038	.025	
0.375–0.499	....	....	.023	.015	.032	.021	.053	.035	
0.500–0.749	....	....	.030	.020	.042	.028	.068	.045	
0.750–0.999	....	....	....	....	.053	.035	.083	.055	
1.000–1.499	....	....	....	....	.068	.045	.098	.065	
1.500–2.000	....	....	....	....	....	....	.113	.075	

OTHER THAN ROUND

Specified Thickness,㉛ Inches	Tolerance,①㉗ Inch, Plus or Minus					
	Allowable Deviation of **Mean** Wall Thickness㉜ from Specified Wall Thickness				Allowable Deviation of Wall Thickness **at Any Point** from Mean Wall Thickness㉜ (Eccentricity)	
	Circumscribing Circle Diameter,㉞ Inch					
	Under 5.000		5.000 and Over		Under 5.000	5.000 and Over
	5083 5086 5456	Other Alloys	5083 5086 5456	Other Alloys	All Alloys	All Alloys
Under 0.047	.008	.005	.012	.008	.005	
0.047–0.061	.009	.006	.014	.009	.007	
0.062–0.124	.011	.007	.015	.010	.010	
0.125–0.249	.012	.008	.023	.015	.015	Plus and minus 10% of mean wall thickness max. ±0.060 min. ±0.010
0.250–0.374	.017	.011	.030	.020	.025	
0.375–0.499	.021	.014	.045	.030	.030	
0.500–0.749	.038	.025	.060	.040	.040	
0.750–0.999	.053	.035	.075	.050	.050	
1.000–1.499	.068	.045	.090	.060	.060	
1.500–2.000	....	....	.105	.070	....	

See pages 296 and 297 for footnotes.

TABLE 92

tube (extruded)

CORNER RADII

Standard Tolerances

Specified Radius, Inches	Allowable Deviation from Specified Radius
Sharp corners	+1/64 inch
Under 0.188	±1/64 inch
0.188 and over	±10%

TABLE 93

tube (extruded)

TWIST and ANGULARITY

Standard Tolerances

TWIST		
Specified Width or Depth (Whichever Greater), Inches	Allowable Deviation from Straight,⑭ Degrees	
	In Each Foot of Length	In Total Length of Piece
Under 1.500	1	Length (ft) x 1
1.500–2.999	1/2	Length (ft) x 1/2 (not over 5)
3.000 and over	1/4	Length (ft) x 1/4 (not over 3)

ANGULARITY—Allowable deviation from specified angle: ±2 degrees.

See page 296 for footnotes.

TABLE 94

tube (extruded)

STRAIGHTNESS

Standard Tolerances

Specified Outside Diameter; Width or Depth (Whichever Greater), Inches	Allowable Deviation⑭⑱ from Straight, Inch	
	In Each Foot of Length	In Total Length of Piece
0.500–5.999	.010	Length (ft) x .010
6.000 and over	.020	Length (ft) x .020

See pages 296 and 297 for footnotes.

TABLE 95

tube (extruded)

LENGTH

Standard Tolerances

Specified Outside Diameter; Width or Depth (Whichever Greater), Inches	Tolerance, Inch, Plus—except as noted			
	Allowable Deviation from Specified Length⑱			
	Straight			
	Specified Length, Feet			
	Up Through 12	Over 12 Through 30	Over 30 Through 50	Over 50
0.500–2.999	1/8	1/4	3/8	1
3.000–7.999	3/16	5/16	7/16	1
8.000 and over	1/4	3/8	1/2	1

See page 296 for footnotes.

TABLE **96**

Tube (drawn)

DIAMETER

Standard Tolerances[1]

Specified Outside or Inside Diameter,[37] Inches	Allowable Deviation from Specified Diameter, Inch, Plus or Minus		
	Mean[38] All Alloys	Individual Measurements at Any Point[39] (Out-of-Roundness)	
		Nonheat-treated Alloys	Heat-treated Alloys[34]
Under 0.501	.003	.003	.006
0.501– 1.000	.004	.004	.008
1.001– 2.000	.005	.005	.010
2.001– 3.000	.006	.006	.012
3.001– 5.000	.008	.008	.016
5.001– 6.000	.010	.010	.020
6.001– 8.000	.015	.015	.030
8.001–10.000	.020	.020	.040
10.001–12.000	.025	.025	.050

See pages 296 and 297 for footnotes.

TABLE **97**

Tube (drawn)

WIDTH and DEPTH

Standard Tolerances[1]

Specified Width or Depth,[37] Inches	Allowable Deviation of Width or Depth from Specified Width or Depth, Inch, Plus or Minus		
	At Corners Square and Rectangular	Not at Corners[35]	
		Square, Hexagonal and Octagonal	Rectangular
Col. 1	Col. 2	Col. 3	Col. 4
Under 0.501	.003	.006	The allowable deviation for the width is the value in column 3 for a dimension equal to the depth, and conversely, but in no case is the allowable deviation less than at the corner.[36]
0.501– 1.000	.004	.008	
1.001– 2.000	.005	.010	
2.001– 3.000	.006	.012	
3.001– 5.000	.008	.016	
5.001– 6.000	.010	.020	
6.001– 8.000	.015	.030	
8.001–10.000	.020	.040	
10.001–12.000	.025	.050	

See pages 296 and 297 for footnotes.

TABLE 98

tube (drawn)

ROUND AND OTHER THAN ROUND

WALL THICKNESS

Standard Tolerances

Specified[37] Wall Thickness (T) Inch	Tolerance, Inch[1][37], Plus or Minus		
	Allowable Deviation of **Mean** Wall Thickness[32] from Specified Wall Thickness	Allowable Deviation of Wall Thickness at **Any Point** from Specified Wall Thickness	
		Round, Nonheat-treatable Alloys[38]	Round, Heat-treatable Alloys[39] and Other-than-round, All Alloys
Col. 1	Col. 2	Col. 3	Col. 4
0.010–0.035	.002	.002	Plus or minus 10% of specified wall thickness, but not less than .003
0.036–0.049	.003	.003	
0.050–0.083	.004	.004	
0.084–0.120	.005	.006	
0.121–0.203	.006	.008	
0.204–0.300	.008	.012	
0.301–0.375	.015	.020	
0.376–0.500	.020	.030	

See pages 296 and 297 for footnotes.

TABLE 99

tube (drawn)

SQUARE—RECTANGULAR HEXAGONAL—OCTAGONAL

TWIST and ANGULARITY

Standard Tolerances

Specified Width or Depth (Whichever Greater), Inches	Allowable Deviation[14] from Straight, Degrees	
	In Each Foot of Length	In Total Length of Piece
Under 1.500	1	Length (ft) x 1
1.500–2.999	½	Length (ft) x ½ (not over 5)
3.000 and over	¼	Length (ft) x ¼ (not over 3)
ANGULARITY—Allowable deviation from specified angle: ±2 degrees.		

See page 296 for footnotes.

TABLE 100

tube (drawn)

SQUARE—RECTANGULAR HEXAGONAL—OCTAGONAL

CORNER RADII

Standard Tolerances

Specified Radius, Inches	Allowable Deviation from Specified Radius
Sharp corners	+1/64 inch
Under 0.188	±1/64 inch
0.188 and over	±10%

TABLE 101

tube (drawn)

STRAIGHTNESS

Standard Tolerances

Specified Outside Diameter; Width or Depth (Whichever Greater), Inches	Allowable Deviation from Straight[14][40], Inch	
	In Each Foot of Length	In Total Length of Piece
Under 0.375	.500	Length (ft) x .500[41]
0.375–5.999	.010	Length (ft) x .010
6.000 and over	.020	Length (ft) x .020

See pages 296 and 297 for footnotes.

TABLE 102

tube (drawn)

LENGTH

Standard Tolerances

Specified Outside Diameter; Width or Depth (Whichever Greater), Inches	Tolerance, Inch, Plus—except as noted							
	Allowable Deviation from Specified Length[18]							
	Straight				Coiled			
	Specified Length, Feet							
	Up Through 12	Over 12 Through 30	Over 30 Through 50	Over 50	100 and Less	101–249	250–499	500 and Over
Under 0.250	1/4	3/8	1/2	..	+5%–0	±10%	±15%	±20%
0.250–1.249	1/8	1/4	3/8	1	+5%–0	±10%	±15%	±20%
1.250–2.999	1/8	1/4	3/8	1	.....	.....	.....	.....
3.000–7.999	3/16	5/16	7/16	1	.....	.....	.....	.....
8.000 and over	1/4	3/8	1/2	1	.....	.....	.....	.....

See page 296 for footnotes.

TABLE 103

pipe

DIMENSIONS

Standard Tolerances

OUTSIDE DIAMETER			STRAIGHTNESS		
Pipe Size, Inches	Allowable Deviation from Nominal[42] Diameter, Inch		Pipe Size, Inches	Tolerance, Inch	
	Schedule 5 and 10[43]	Schedule 20[43] and Heavier		Allowable Deviation from Straight	
				In Each Foot of Length	In Total Length of Piece
Under 2	+.015–.031	+.015–.031	Under 6	.010	.010 x length (ft)
2–4	+.031–.031	+ 1%– 1%	6–12	.020	.020 x length (ft)
4½–7	+.062–.031	+ 1%– 1%			
8–12	+.093–.031	+ 1%– 1%			

WALL THICKNESS: Allowable deviation of wall thickness at any point from normal wall thickness[42]: Minus 12½ per cent. (Maximum wall thickness is controlled by weight tolerance.)
LENGTH: Allowable deviation from specified length: Plus ¼ inch. Applies only to lengths 20 feet and under. For lengths over 20 to 40 feet, plus ½ inch applies.
WEIGHT: Allowable deviation from theoretical weight: Plus 8 per cent. (Minimum weight is controlled by tolerances for outside diameter and wall thickness.) (For Schedule 5 and 10, only diameter, wall thickness and length tolerances apply.)
See page 297 for footnotes.

NOTES FOR TABLES 61 TO 103

① When a dimension tolerance is specified other than as an equal bilateral tolerance, the value of the standard tolerance is that which would apply to the mean of the maximum and minimum dimensions permissible under the tolerance.

② Sheet has a thickness of less than 0.250 inch.

③ Plate has a thickness of 0.250 inch and greater.

④ Product sizes listed on this page do not necessarily indicate availability.

⑤ For flat sheet in thicknesses of 0.201 inch to 0.249 inch the minimum width which can be sheared is 5 inches. Narrower widths subject to special inquiry.

⑥ Lateral bow is defined as the curvature of the edge of a sheet or plate and is measured as the perpendicular distance from the point of maximum departure of the curved edge from a straight line joining the extremities of the edge.

⑦ Subject to special inquiry.

⑧ Widths less than 0.375 inch (except flattened wire) are wire.

⑨ Widths 0.375 inch or greater are bar.

⑩ Specified thickness of 0.187 to 0.500 inch.

⑪ Not applicable to material in the annealed (O) temper, to forging stock, or to coiled material.

⑫ For thicknesses under 0.095 inches, tolerance applies when weight of section on flat surface minimizes curvature.

⑬ The circumscribed circle diameter is the diameter of the smallest circle that will completely enclose the shape.

⑭ Not applicable in the "O" temper.

⑮ Closer tolerances subject to inquiry.

⑯ For "Standard 12-foot Lengths," the length tolerance is plus or minus ½ inch.

⑰ Certain structural shapes, if produced by extrusion, will require tolerances wider than those indicated.

⑱ Squareness of cut ends: 1 degree.

⑲ The tolerance applicable to a dimension composed of two or more component dimensions is the sum of the tolerances of the component dimensions, if all of the component dimensions are indicated.

⑳ At points less than ¼ inch from base of leg, the tolerances in Col. 2 are applicable.

㉑ Where the space is completely enclosed (hollow shapes), the tolerance for the width is the value in Col. 4 for a dimension equal to the depth, and conversely, but in no case is the tolerance less than at the corners (Col. 2). Example: The width tolerance of a hollow shape having 1 x 3 inch rectangular outside dimensions is ± 0.024 inch and the depth tolerance is ± 0.032 inch. Tolerance at the corners (Col. 2) is ± 0.024 for the width and ± 0.012 inch for the depth.

㉒ In the case of Class 1 Hollow Shapes, the standard wall thickness tolerance for round Extruded Tube is applicable.

㉓ Applicable to the **mean** wall thickness, where the dimensions specified are outside and inside, rather than the wall thickness itself. The "mean wall thickness" is determined by the average of two wall thickness measurements taken at opposite sides of the void.

㉔ These standard tolerances are applicable to the average shape: wider tolerances may be required for some shapes and closer tolerances may be possible for others.

(25) When weight of shape on flat surface minimizes deviation.

(26) Applicable to straight length only.

(27) When outside diameter, inside diameter and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

(28) Mean diameter is the average of any two measurements of diameter taken at right angles to each other.

(29) Not applicable in the annealed "O" temper or if wall thickness is less than 2½ per cent of the outside diameter or the equivalent round diameter. The equivalent round diameter is the diameter of a circle having a circumference equal to the perimeter of a shape.

(30) Example: The width tolerance for a 1 x 3 inch rectangular tube is ± 0.025 inch and the depth tolerance is ± 0.035 inch.

(31) Where dimensions specified are outside and inside, rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±15% of mean wall thickness: ±0.090 in. maximum, ±0.015 in. minimum for 5083, 5086 and 5456 alloys; and plus or minus 10 per cent of the mean wall thickness: maximum ±0.060 inch, minimum ±0.010 inch for other alloys.

(32) The mean wall thickness of round tube is the average of two measurements taken opposite each other. The mean wall thickness of other-than-round tube is the average of two measurements taken opposite each other at approximate center line of tube and perpendicular to the longitudinal axis of the cross section.

(33) For all sizes of other-than-round tube, tolerance is applicable when weight of tube on flat surface minimizes deviation.

(34) For the —T8 tempers of 6063, the tolerances under nonheat-treated alloys apply.

(35) Not applicable to annealed (O) temper tubes, coiled tubes or tubes having a wall thickness less than 0.020 inch or less than 2½ per cent of the outside diameter or the equivalent round diameter. The equivalent round diameter is the diameter of a circle having a circumference equal to the perimeter of the shape.

(36) Example: The width tolerance for a 1 x 3 inch rectangular tube is ± 0.008 inch and the depth tolerance is ± 0.012 inch.

(37) Where dimensions specified are outside and inside, rather than wall thickness itself, allowable deviation at any point (eccentricity) is plus or minus 10 per cent of the mean wall thickness, but not less than 0.003 inch.

(38) For coiled tube, values of Col. 4 apply.

(39) For the —T8 tempers of 6063 round tube, the tolerances in Col. 3 apply.

(40) For round tube under 0.375 inch diameter and for all sizes of other-than-round tube, tolerance is applicable when weight of tube on flat surface minimizes deviation.

(41) Not applicable to lengths less than 10 feet.

(42) Nominal diameter and wall thickness are those listed in ASA Standard B36.10—1950.

(43) For bare and Alclad 2024 in the -T36 and -T86 in widths over 60 thru 84 inches, the tolerance is .001 inches greater than quoted for the thickness range 0.077-0.125 inches.

(44) Hexagons available up to 3.000 inches, incl.

(45) Rolled bar applies only to squares. Tolerance applies to over-all dimensions of bar. Corners may be somewhat rounded and the faces may not be entirely flat.

(46) Not applicable to edge surfaces.

(47) Tolerance applies to over-all dimensions of bar. Corners may be somewhat rounded and the width face not entirely flat.

(48) Allowable deviation of Pi-tape diameter or mean diameter defined as the average of two diameter measurements taken at right angles to each other in the same transverse plane.

(49) Allowable deviation of diameter at any point from nominal.

TABLE
104

sheet and plate

ALCOA MILL STANDARD SIZES

Alloys: 1100, 3003, 5052

Thickness Inch	1100-O	1100-H14	3003-O	3003-H14	1 side brt. mill fin. 3003-H25	5052-O & -H34	5052-H32
.016	24x 72	24x 72	.....	24x 72	.....	.....	.....
	24x 72	24x 72	.....	24x 72	.....	.....	.....
.020	.....	36x 96	.....	36x 96	36x 96	36x 96	36x 96
	.....	.....	.....	36x120	.....	.....	.....
	.....	.....	.....	.....	.....	.....	36x144
	24x 72	24x 72	.....	.....	.....	.....	.....
.025	.....	36x 96	36x 96	36x 96	36x 96	36x 96	36x 96
	.....	.....	.....	36x120	.....	.....	.....
	.....	.....	.....	.....	.....	.....	36x144
	24x 72	24x 72	.....	.....	.....	.....	.....
	36x 96	36x 96	36x 96	36x 96	36x 96	.....	36x 96
.032	.....	.....	.....	36x120	.....	.....	.....
	.....	.....	.....	.....	.....	.....	48x 96
	.....	.....	.....	48x120	.....	.....	.....
	.....	48x144	.....	48x144	.....	48x144	48x144
	24x 72	24x 72	.....	.....	.....	.....	.....
	36x 96	36x 96	36x 96	36x 96	36x 96	.....	36x 96
	.....	.....	.....	36x120	.....	.....	.....
.040	.....	.....	.....	.....	.....	.....	48x 96
	.....	.....	.....	48x120	.....	.....	.....
	48x144	48x144	48x144	48x144	48x144	48x144	48x144
	.....	.....	.....	60x144	.....	.....	.....
	24x 72	24x 72	.....	.....	.....	.....	.....
	36x 96	36x 96	36x 96	36x 96	36x 96	.....	36x 96
	.....	.....	.....	36x120	.....	.....	.....
.050	.....	.....	.....	.....	.....	.....	48x 96
	.....	.....	.....	48x120	.....	.....	.....
	48x144	48x144	48x144	48x144	48x144	48x144	48x144
	.....	.....	.....	60x144	.....	.....	.....
	24x 72	24x 72	.....	.....	.....	.....	.....
	36x 96	36x 96	36x 96	36x 96	36x 96	.....	36x 96
	.....	.....	.....	36x120	.....	.....	.....
.063	.....	.....	.....	.....	.....	.....	48x 96
	.....	.....	.....	48x120	.....	.....	.....
	48x144	48x144	.....	48x144	48x144	48x144	48x144
	.....	.....	.....	60x144	.....	.....	.....
	36x 96	36x 96	36x 96	36x 96	.....	.....	36x 96
.080	.....	.....	.....	.....	.....	.....	48x 96
	.....	48x144	48x144	48x144	.....	48x144④	48x144
	36x 96	36x 96	36x 96	36x 96	.....	.....	36x 96
.090	.....	.....	.....	.....	.....	.....	48x 96
	.....	48x144	48x144	48x144	.....	48x144④	48x144
	36x 96	36x 96	36x 96	36x 96	.....	.....	36x 96
.125	.....	48x144	48x144	48x144	.....	48x144④	48x144
.190	.....	36x 96①	.....	36x 96①	.....	.....	36x 96③
	.....	48x144①	.....	48x144①	.....	48x144	48x144③
.250	36x 96②	.....	36x 96③	.....	.....	.....	.....
	48x144③	.....	48x144③	.....	.....	48x144③	.....
.313	36x 96③	.....	.....	.....	.....	.....	.....
.375	36x 96②	.....	.....	.....	.....	.....	.....
.500	36x 96③	.....	.....	.....	.....	.....	.....

①Supplied in -H24 temper only.
②Supplied in -F temper only.
③Supplied in -H22 temper only.
④Also supplied in -H24 temper.

TABLE 105

sheet and plate

ALCOA MILL STANDARD SIZES

Alloys: 2024, Alclad 2024, 6061, Alclad 7075, 7178

Thickness, Inch	2024-O, -T3 Alclad 2024-O, -T3	6061-O -T4 and -T6	Alclad 7075-O and -T6	7178-O and -T6
0.016⑦	36 x 144④	.....	.....	.....
0.020⑦	36 x 144④	.....	36 x 144	36 x 144
0.025⑦	48 x 144	36 x 144	36 x 144 48 x 144	36 x 144
0.032⑦	48 x 144 60 x 180	48 x 144	48 x 144 60 x 180	48 x 144
0.040⑦	48 x 144 60 x 180	48 x 144	48 x 144 60 x 180	48 x 144
0.050⑦	48 x 144 60 x 180	48 x 144	48 x 144 60 x 180	48 x 144
0.063⑦	48 x 144 60 x 180	48 x 144	48 x 144 60 x 180	48 x 144
0.071⑦	48 x 144 60 x 180	.....	48 x 144 60 x 180	48 x 144
0.080⑦	48 x 144 60 x 180	48 x 144③	48 x 144 60 x 180	48 x 144
0.090⑦	48 x 144 60 x 180	48 x 144②	48 x 144 60 x 180	48 x 144
0.100⑦	48 x 144 60 x 180	48 x 144③	48 x 144 60 x 180	48 x 144
0.125⑦	48 x 144 60 x 180	48 x 144③	48 x 144 60 x 180	48 x 144
0.160⑦	48 x 144 60 x 180	48 x 144③	48 x 144 60 x 180	48 x 144
0.190⑦	48 x 144 60 x 180	48 x 144②	48 x 144 60 x 180	48 x 144
0.250	36 x 96① 48 x 144③ 60 x 180③	48 x 144③	48 x 144③ 60 x 180③	48 x 144
0.313	36 x 96①	.....	.....	.....
0.375	36 x 96①	48 x 96③ 48 x 144③ 60 x 144③	....	....
0.500	....	36 x 96③ 48 x 96③ 60 x 144③	....	....
0.625	....	48 x 96③ 48 x 144③ 60 x 144③	....	....
0.750	....	48 x 96③ 48 x 144③ 60 x 144③	....	....
1.000	....	48 x 96③ 48 x 144③ 60 x 144③	....	....
1.250	....	48 x 96③ 48 x 144③ 60 x 144③	....	....
1.500	....	48 x 96③ 48 x 144③ 60 x 144③	....	....

See page 300 for footnotes.

TABLE 105

sheet and plate

ALCOA MILL STANDARD SIZES

Alloys: 2024, Alclad 2024, 6061, Alclad 7075, 7178

Continued

Thickness, Inch	2024-O, -T3 Alclad 2024-O, -T3	6061-O -T4 and -T6	Alclad 7075-O and -T6	7178-O and -T6
1.750	.....	48 x 96⑨	.....	.....
	.....	48 x 144⑨	.....	.....
	.....	60 x 144⑨	.....	.....
2.000	.....	48 x 96⑨	.....	.....
	.....	48 x 144⑨	.....	.....
	.....	60 x 144⑨	.....	.....
2.500	.....	48 x 96⑨	.....	.....
	.....	48 x 144⑨	.....	.....
	.....	60 x 144⑨	.....	.....
3.000	.....	48 x 96⑨	.....	.....
	.....	48 x 144⑨	.....	.....
	.....	60 x 144⑨	.....	.....

①Supplied bare and in -T351 temper only.
②Supplied in -O and -T6 tempers only.
③Supplied in -T6 temper only.
④Supplied alclad only.
⑤Supplied in -O and -T351 tempers.
⑥Not available bare in the -O temper.
⑦Also available in Skin Quality Finish.
⑧Supplied in -O and -T651 temper only.
⑨Supplied in -T651 temper only.

TABLE 106

sheet

COMMERCIAL SIZES①

Alloys: 1100, 3003, Alclad 3003, 5005

Thickness,④ Inch	Maximum Commercial Rolling Limits②③			
	1100, 3003, 5005		Alclad 3003	
	Width, Inches	Length, Feet	Width, Inches	Length, Feet
0.249–0.096	102	30	60	30
0.095–0.068	96	30	60	30
0.067–0.061	96	30	60	30
0.060–0.043	90	30	60	30
0.042–0.038	90	30	60	30
0.037–0.030	60	20	60	20
0.029–0.024	48	16	48	16
0.023–0.019	48	16	36	16
0.018–0.015	36	12	36	12
0.014–0.012	36	12	....	....
0.011–0.0095	30	12	....	....
0.009–0.007	24	8	....	....
0.006	18	8	....	....

①Refer to Table 104 for Alcoa Mill Standard Sizes.
②Maximum diameter of circle same as maximum width of sheet.
③Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
④Maximum thickness for -H18 temper is 0.128 inch.
Maximum thickness for -H16 temper is 0.162 inch.
Minimum thickness for -H14 temper is 0.0095 inch. (0.016 inch in Alclad 3003.)
Minimum thickness for -H12 temper is 0.017 inch. (0.020 inch in Alclad 3003.)

TABLE 107

sheet

COMMERCIAL SIZES①

Alloys: 5357, 5457 and 5557

Thickness,④ Inch	Maximum Commercial Rolling Limits②③	
	Width, Inches	Length, Feet
Under–Incl.		
0.250–0.136	60	30
0.136–0.096	60	30
0.096–0.077	60	30
0.077–0.061	60	30
0.061–0.048	60	30
0.048–0.038	60	30
0.038–0.030	60	20
0.030–0.024	60	16
0.024–0.019	48	16
0.019–0.017	48	12
0.017–0.015	48	12
0.015–0.014	36	12
0.014–0.012	36	12
0.012–0.011	36	12
0.011–0.0095	36	12
0.0095–0.0085	36	8
0.0085–0.0075	36	8
0.0075–0.007	36	8
0.007 –0.006	36	8

①Refer to Table 104 for Alcoa Mill Standard Sizes.
②Maximum diameter of circle same as maximum width of sheet.
③Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
④Available in -O, -H25, -H26 tempers only.

TABLE 108

sheet

COMMERCIAL SIZES①

Alloys: 6061-O, 6061-T4, 6061-T6
Alclad 6061-O, -T4, -T6

Thickness, Inch	Maximum Commercial Rolling Limits②③		
	Width, Inches		Length, Feet
	6061	Alclad 6061	
0.249–0.136	102	60	30
0.135–0.068	102	60	30
0.067–0.061	84	60	30
0.060–0.048	84	60	24
0.047–0.038	60	60	24
0.037–0.030	60	60	18
0.029–0.024	48	..	16
0.023–0.019	36	..	16
0.018–0.015	36	..	14
0.014–0.0095	30	..	14

①Refer to Table 105 for Alcoa Mill Standard Sizes.
②Maximum diameter of circle same as maximum width of sheet.
③Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.

TABLE 109

sheet

COMMERCIAL SIZES

Alloys: 1100 and 3003
5357[5], 5457[5], 5557[5]

Thickness, Inch	Maximum Commercial Rolling Limits [1]					
	Standard Bright Finish (Two Sides)[2]		Standard One-side Bright Finish[3]		One-Side Bright Mill Finish[4][6]	
	Width, Inches	Length, Feet	Width, Inches	Length, Feet	Width, Inches	Length, Feet
0.250–0.136	60	20	..	..	..	..
0.135–0.096	60	20	..	..	..	..
0.095–0.077	60	20	..	..	48	20
0.076–0.061	60	20	36	20	48	20
0.060–0.048	54	20	36	20	48	20
0.047–0.038	54	20	36	20	48	20
0.037–0.030	54	20	36	20	48	20
0.029–0.024	54	16	36	16	48	16
0.023–0.019	54	16	36	16	36	16
0.018–0.017	48	12	30	12	36	12
0.016–0.015	48	12	30	12	36	12
0.014	42	12	30	12	24	12
0.013–0.012	36	12	30	12	24	12
0.011	36	12	24	12	24	12
0.010–0.0095	36	12	24	12	24	12
0.0094–0.006	36	12	24	8	24	8

[1] Sizes greater than indicated can be supplied in some cases; consult nearest Alcoa sales office.
[2] Available in -O, -H12, -H14, -H25, -H16, -H26 and -H18 tempers except that maximum thickness for -H18 is 0.128 inch and for -H16 is 0.162 inch. Minimum thickness for -H12 is 0.017 inch.
[3] Available in -O and -H18 tempers in all thicknesses. in -H16 in thicknesses 0.006 through 0.025 inch, in -H14 and -H25 in thicknesses 0.0095 through 0.042 inch, in -H12 in thicknesses 0.017 through 0.042 inch, and in -H26 in thicknesses 0.006 through 0.053 inch.
[4] Available in -O and -H18 tempers in all thicknesses, in -H14 in thicknesses 0.0095 through 0.011, in -H25 and -H26 in thicknesses 0.0095 through 0.081, and in -H16 in thicknesses 0.006 through 0.011.
[5] Available only in One-Side Bright Mill finish.
[6] Alloys 5357, 5457, 5557 available in -O, -H25, and -H26 tempers in all thicknesses. For availability of other tempers consult nearest Alcoa sales office.

TABLE 110

sheet

COMMERCIAL SIZES[1]

Alloys: 2024-T36, and
Alclad 2024-T36

Thickness, Inch	Maximum Commercial Rolling Limits,[2][3] Width, Inches	
	Lengths up to 12 Feet, Inclusive	Lengths over 12 Feet through 18 Feet
0.375–0.077	60	60
0.076–0.061	48	48
0.060–0.030	48	36
0.029–0.024	30	..
0.023–0.019	24	..

[1] Refer to Table 105 for Alcoa Mill Standard Sizes.
[2] Maximum diameter of circle same as maximum width of sheet.
[3] Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.

TABLE 111

sheet

COMMERCIAL SIZES[1]

Alloys: 3004, Alclad 3004, 5050, 5052, 5154, 5454, 5086, 5083, 5456

Thickness,[2] Inch	Maximum Commercial Rolling Limits[3][4]					
	3004, 5050, 5052		Alclad 3004		5154, 5454, 5086, 5083, 5456	
	Width, Inches	Length, Feet	Width, Inches	Length, Feet	Width, Inches	Length, Feet
0.249–0.172	102	30	60	24	96	30
0.171–0.136	102	30	60	24	96	30
0.135–0.096	90	30	60	24	84	30
0.095–0.086	90	30	60	24	84	30
0.085–0.077	84	30	60	24	72	30
0.076–0.061	84	24	60	24	72	24
0.060–0.048	84	24	60	20	60	24
0.047–0.038	84	18	60	18	60	18
0.037–0.030	72	18	48	18	54	18
0.029–0.024	60	16	36	16	48	16
0.023–0.019	48	16	..	..	36	16
0.018–0.015	36	12	..	..	36	12
0.014–0.012	36	8	..	..	36	8
0.011–0.0095	36	8	..	..	..	..
0.009–0.0075	36	8	..	..	..	..
0.007	36	8	..	..	..	..
0.006	36	8	..	..	..	..

[1] Refer to Table 104 for Alcoa Mill Standard Sizes.
[2] Maximum thickness for -H38 temper is 0.128 inch and for -H36 is 0.162 inch.
Minimum thickness for -H34 temper is 0.0095 inch and for -H32 is 0.017 inch. (0.032 and 0.040 inch, respectively, in Alclad 3004.)
Minimum thickness for -O and -H36 tempers of Alclad 3004 is 0.025 inch.
[3] Maximum diameter of circle same as maximum width of sheet. Circles larger than 96 inches in diameter are sawed.
[4] Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.

TABLE 112

sheet

FLAT—MILL FINISH

COMMERCIAL SIZES[1]

Alloys: Alclad 2014-O, -T3, -T6
Alloys: 2024-O, 2024-T3, Alclad 2024-O, Alclad 2024-T3
Alloys: 7075-O, 7075-T6, Alclad 7075-O, Alclad 7075-T6, 7178

Thickness, Inch	Maximum Commercial Rolling Limits[2][3]	
	Width, Inches	Length, Feet
0.249–0.156	96	30
0.155–0.061	84	30
0.060–0.040	84	24
0.039–0.024	60	18
0.023–0.019	48	16
0.018–0.015	36	14
0.014–0.0095	36	14

[1] Refer to Table 105 for Alcoa Mill Standard Sizes.
[2] Maximum diameter of circle same as maximum width of sheet.
[3] Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.

TABLE 113

sheet

COMMERCIAL WIDTHS

Alloys: 1100, 3003, Alclad 3003, 5050

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches		Available Tempers
	1100, 3003 and 5050	Alclad 3003	
0.125 –0.103	90	48	O, H12, H18
0.102 –0.096	90	48	O, H12, H14, H18
0.095 –0.082	90	48	O, H12, H14, H16, H18
0.081 –0.038	90	48	O, H12, H14, H16, H18
0.037 –0.030	90	48③	O, H12, H14, H16, H18
0.029 –0.024	60	48④	O, H12, H14, H16, H18
0.023 –0.019	48	36④	O⑤, H12, H14, H16, H18
0.018 –0.017	48	36	O⑤, H12⑥, H14, H16, H18
0.016 –0.015	48	36	O⑤, H14⑦, H16, H18
0.014 –0.0095	60	36	O⑤, H14⑦, H16⑧, H18
0.009 –0.008	60	36	O⑤, H16⑧, H18
0.0075–0.007	60	36	O⑤, H16⑧, H18
0.006	60	36	O⑤, H16⑧, H18

①Maximum diameter of circle is 36 inches.
②Widths greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
③Maximum in -H12 temper is 36 inches.
④Maximum in -H12 temper is 24 inches.
⑤Available only as circles in Alclad 3003.
⑥Not available in Alclad 3003.
⑦Minimum thickness in Alclad 3003 is 0.016 inch.
⑧Minimum thickness in Alclad 3003 is 0.012 inch.

TABLE 114

sheet

COMMERCIAL WIDTHS

Alloys: 5357, 5457 and 5557

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches	Available Tempers③
Under–Incl.		
0.126–0.096	60	O, H25, H26
0.096–0.077	60	O, H25, H26
0.077–0.061	60	O, H25, H26
0.061–0.048	60	O, H25, H26
0.048–0.038	60	O, H25, H26
0.038–0.030	60	O, H25, H26
0.030–0.024	48	O, H25, H26
0.024–0.019	36	O, H25, H26
0.019–0.017	36	O, H25, H26
0.017–0.015	36	O, H25, H26
0.015–0.014	36	O, H25, H26
0.014–0.012	36	O, H25, H26
0.012–0.011	36	O, H25, H26
0.011–0.0095	36	O, H25, H26
0.0095–0.0085	36	O, H26
0.0085–0.0075	36	O, H25, H26
0.0075–0.007	36	O, H25, H26
0.007 –0.006	36	O, H25, H26

①Maximum diameter of circle is 36 inches.
②Widths greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
③Also available in -H32, -H34, -H36, -H38 except
-H32 temper—Minimum thickness 0.017 inch.
-H34 temper—Minimum thickness 0.0095 inch.

TABLE 115

sheet

COMMERCIAL WIDTHS

Alloys: 3004, Alclad 3004, 5052

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches		Available Tempers③
	Alclad 3004	3004 and 5052	
0.125–0.103	60	90	O, H32, H38
0.102–0.096	60	90	O, H32, H34, H38
0.095–0.077	60	90	O, H32, H34, H36, H38
0.076–0.030	36	90	O, H32, H34, H36, H38
0.029–0.017	36	48	O, H32, H34, H36, H38
0.016–0.015	36	36	O, H34, H36, H38
0.014–0.012	36	36	O, H34, H36, H38
0.011–0.0095	36	60	O, H34, H36, H38
0.009–0.007	36	60	O, H36, H38
0.006	36	60	O, H36, H38

①Maximum diameter of circle is 24 inches.
②Widths greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
③In Alclad 3004, the maximum thickness in the -H36 temper is 0.072 inch and in the -H34 temper is 0.085 inch. The minimum thickness in the -H36 temper is 0.025 inch, in the -H34 temper is 0.032 inch, and in the -H32 temper is 0.040 inch.

TABLE 116

sheet

COMMERCIAL WIDTHS

Alloys: Alclad 2014, 2024, Alclad 2024, 6061, Alclad 6061, 7075, Alclad 7075, 7178, Alclad 7178

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches	
	-T4 or -T6	-O or -F
0.102–0.082	..	60
0.081–0.030	24	60
0.029–0.024	22	48④
0.023–0.019	22	36
0.018–0.015	12③	36③
0.014–0.012	12③	24③

①Maximum diameter of circle is 26 inches.
②Widths greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
③Minimum thickness for Alclad 2014 is 0.019 inch, and for 7075 and Alclad 7075 is 0.015 inch.
④Maximum for Alclad 2014, 7075 and Alclad 7075 is 36 inches.

TABLE 117

COMMERCIAL WIDTHS

Alloys: 1100 and 3003
5357④, 5457④, 5557④

ONE-SIDE BRIGHT MILL FINISH

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches	Available Tempers
0.081–0.054	48	O, H18, H25, H26
0.053–0.038	48	O, H18, H25, H26
0.037–0.024	48	O, H18, H25, H26
0.023–0.017	36	O, H18, H25, H26
0.016–0.015	36	O, H18, H25, H26
0.014–0.012	36	O, H18, H25, H26
0.011–0.0095	24	O, H14, H16, H18, H25, H26
0.009	24	O, H16, H18, H25, H26
0.0085	24	O, H16, H18
0.008–0.0075	24	O, H16, H18
0.007	24	O, H16, H18
0.006	24	O, H16, H18

ALLOYS 1100 and 3003

STANDARD ONE-SIDE BRIGHT FINISH

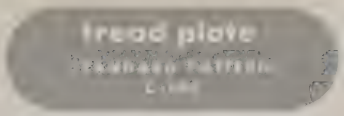
Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches	Available Tempers③
0.064–0.054	36	O, H18
0.053–0.043	36	O, H18, H26
0.042–0.017	36	O, H12, H18, H25, H26
0.016–0.015	30	O, H18, H25, H26
0.014–0.012	30	O, H18, H25, H26
0.011–0.0095	24	O, H18, H25, H26
0.009–0.0085	24	O, H18, H26
0.008–0.007	24	O, H18, H26
0.006	18	O, H18, H26

STANDARD BRIGHT FINISH (TWO SIDES)

Thickness, Inch	Maximum Commercial Rolling Limits,①② Inches	Available Tempers③
0.051–0.043	36	O, H18, H26
0.042–0.017	36	O, H12, H18, H25, H26
0.016–0.0095	24	O, H18, H25, H26

①Maximum diameter of circle is 36 inches.
②Widths greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
③Also available in -H14 temper in thicknesses from 0.0095 through 0.042 inch and in -H16 temper in thicknesses from 0.006 through 0.025 inch.
④Alloys 5357, 5457, 5557 available in -O, -H25 and -H26 tempers in all thicknesses. For availability of other tempers consult nearest Alcoa sales office.

TABLE 118



COMMERCIAL SIZES

Alloys: 6061-O, 6061-F, 6061-T4, 6061-T6

Thickness, Inch	Mill Standard Sizes,② Inches	Maximum Commercial Rolling Limits①		Approximate Weight, Lb/Sq Ft
		Width, Inches	Length, Feet	
0.100	.....	60	24	1.6
0.125	48 x 192	60	24	1.9
	60 x 192	60	24	1.9
0.156	48 x 192	72	24	2.2
	60 x 192	72	24	2.2
0.188	48 x 192	72	24	2.8
	60 x 192	72	24	2.8
0.250	48 x 192	72	24	3.7
	60 x 192	72	24	3.7
0.375	.....	72	24	5.5
0.500	.....	72	24	7.3

①Sizes greater than indicated can be supplied in certain cases; consult nearest Alcoa sales office.
②Applies to -T4 and -T6 tempers only.

TABLE 119 plate

MAXIMUM COMMERCIAL SIZES①③

Alloys: 1100 and 3003; Tempers: -F, -O, -H112

Thickness,③④ Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Inches (Feet)	Maximum Length in Inches (Feet) for Indicated Widths						
			Width, 48 Inches	Width, 60 Inches	Width, 72 Inches	Width, 84 Inches	Width, 96 Inches	Width, 108 Inches	Width, 120 Inches
0.250	120	480 (40.0)	480	480	480	480	480	480	480
0.375	132	480 (40.0)	480	480	480	480	480	480	480
0.500	136	540 (45.0)	540	540	540	540	540	540	540
0.625	136	540 (45.0)	540	540	540	540	540	540	540
0.750	136	492 (41.0)	540	540	540	540	540	540	540
0.875	136	420 (35.0)	540	540	540	540	540	528	474
1.000	136	366 (30.5)	540	540	540	540	516	468	420
1.250	136	294 (24.5)	540	540	540	480	420	372	336
1.500	136	246 (20.5)	540	540	462	396	348	306	276
1.750	136	210 (17.5)	540	480	396	336	300	264	240
2.000	136	180 (15.0)	516	420	348	300	264	228	204
2.250	136	162 (13.5)	462	372	300	264	228	204	186
2.500	136	144 (12.0)	420	336	276	240	204	186	168
2.750	136	132 (11.0)	378	300	252	216	192	168	150
3.000	136	120 (10.0)	348	276	232	198	174	156	138

①②③④See page 313.

TABLE 120

plate
MILL FINISH

MAXIMUM COMMERCIAL SIZES①②

Alloys: 3004, 5050, 5052, 5154, 5454; Tempers: -F, -O, -H112

Thickness,③④ Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Inches (Feet)	Maximum Length in Inches (Feet) for Indicated Widths						
			Width, 48 Inches	Width, 60 Inches	Width, 72 Inches	Width, 84 Inches	Width, 96 Inches	Width, 108 Inches	Width, 120 Inches
0.250	102	480 (40.0)	480	480	480	480	480	480	480
0.375	120	480 (40.0)	480	480	480	480	480	480	480
0.500	132	540 (45.0)	540	540	540	540	540	540	540
0.625	132	540 (45.0)	540	540	540	540	540	540	540
0.750	132	504 (42.0)	540	540	540	540	540	540	540
0.875	132	432 (36.0)	540	540	540	540	540	474	426
1.000	132	378 (31.5)	540	540	540	540	468	420	372
1.250	132	300 (25.0)	540	540	540	420	360	336	300
1.500	132	252 (21.0)	540	540	420	348	312	276	246
1.750	132	216 (18.0)	540	420	348	300	264	240	216
2.000	132	192 (16.0)	468	372	312	264	228	204	192
2.250	132	168 (14.0)	420	336	276	240	204	180	168
2.500	132	150 (12.5)	372	300	252	216	180	168	150
2.750	132	138 (11.5)	336	276	228	192	168	150	138
3.000	132	126 (10.5)	312	240	204	180	156	138	126

①②③④See page 313.

TABLE 121

plate
MILL FINISH

MAXIMUM COMMERICAL SIZES①②

Alloys: 5086, 5083, 5456

Thickness,③④ Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Inches (Feet)	Maximum Length in Inches (Feet) for Indicated Widths					
			Width, 48 Inches	Width, 60 Inches	Width, 72 Inches	Width, 84 Inches	Width, 96 Inches	Width, 108 Inches
0.250	96	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	. . . . .	. . . . .
0.375	96	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	. . . . .	. . . . .
0.500	102	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	480 (40.0)	. . . . .
0.625	120	480 (40.0)	480 (40 0)	480 (40.0)	480 (40 0)	480 (40 0)	480 (40.0)	480 (40.0)
0.750	120	498 (41.5)	720 (60.0)	720 (60.0)	720 (60.0)	720 (60.0)	624 (52.0)	552 (46.0)
0.875	120	426 (35.5)	720 (60.0)	720 (60.0)	720 (60 0)	612 (51.0)	528 (44.0)	480 (40.0)
1.000	120	372 (31.0)	720 (60.0)	720 (60.0)	624 (52 0)	528 (44 0)	468 (39 0)	420 (35.0)
1.250	120	300 (25.0)	600 (50.0)	600 (50.0)	492 (41.0)	420 (35.0)	360 (30.0)	336 (28.0)
1.500	120	246 (20.5)	600 (50 0)	492 (41 0)	420 (35.0)	348 (29.0)	312 (26.0)	276 (23.0)
1.750	120	216 (18.0)	540 (45.0)	420 (35.0)	348 (29.0)	300 (25 0)	264 (22.0)	240 (20.0)
2.000	120	192 (16.0)	468 (39.0)	372 (31.0)	312 (26.0)	264 (22.0)	228 (19.0)	204 (17.0)
2.250	120	168 (14.0)	420 (35 0)	336 (28.0)	276 (23.0)	240 (20.0)	204 (17.0)	180 (15.0)
2.500	120	150 (12.5)	372 (31.0)	300 (25.0)	252 (21.0)	216 (18.0)	180 (15.0)	168 (14.0)
2.750	120	138 (11.5)	336 (28.0)	276 (23.0)	228 (19.0)	192 (16.0)	168 (14.0)	150 (12.5)
3.000	120	126 (10.5)	312 (26.0)	240 (20.0)	204 (17.0)	180 (15.0)	156 (13.0)	138 (11.5)

①②③④See page 313.

TABLE
122

plate
MILL FINISH

MAXIMUM COMMERCIAL SIZES①②

Alloy: 6061; Tempers: -F, -O, -T4, -T6

Thickness,③④ Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Inches (Feet)	Maximum Length in Inches (Feet) for Indicated Widths					
			Width, 48 Inches	Width, 60 Inches	Width, 72 Inches	Width, 84 Inches	Width, 96 Inches	Width, 108 Inches
0.250	102	468 (39.0)	468	468	468	468	. . .	. . .
0.375	102	468 (39.0)	468	468	468	468	. . .	. . .
0.500	120	468 (39.0)	468	468	468	468	468	468
0.625	120	468 (39.0)	468	468	468	468	468	468
0.750	120	468 (39.0)	468	468	468	468	468	468
0.875	120	456 (38.0)	468	468	468	468	468	468
1.000	120	402 (33.5)	468	468	468	468	468	420
1.250	120	329 (27.0)	468	468	468	420	360	336
1.500	120	264 (22.0)	468	468	420	348	312	276
1.750	120	228 (19.0)	468	420	348	300	264	240
2.000	120	204 (17.0)	468	372	312	264	228	204
2.250	120	180 (15.0)	420	336	276	240	204	180
2.500	120	162 (13.5)	372	300	252	216	180	168
2.750	120	144 (12.0)	336	276	228	192	168	150
3.000	120	132 (11.0)	312	240	204	180	156	138

①②③④See page 313.

TABLE 123

plate
MILL FINISH

MAXIMUM COMMERCIAL SIZES①②

Alloys: Alclad 2014, 2024, Alclad 2024, 7075, Alclad 7075;
Tempers: -F, -O, -T4, -T6

Thickness,③④ Inches	Maximum Width, Inches	Maximum Length for Maximum Width, Inches (Feet)	Maximum Length in Inches (Feet) for Indicated Widths					
			Width, 48 Inches	Width, 60 Inches	Width, 72 Inches	Width, 84 Inches	Width, 96 Inches	Width, 108 Inches
0.250	102	468 (39.0)	468	468	468	468	468	468
0.375	102	468 (39.0)	468	468	468	468	468	468
0.500	120	468 (39.0)	468	468	468	468	468	468
0.625	120	468 (39.0)	468	468	468	468	468	468
0.750	120	468 (39.0)	468	468	468	468	468	468
0.875	120	456 (38.0)	468	468	468	468	468	468
1.000	120	402 (33.5)	468	468	468	468	468	462
1.250	120	329 (27.0)	468	468	468	468	414	366
1.500	120	264 (22.0)	468	468	462	396	348	312
1.750	120	228 (19.0)	468	468	396	336	294	264
2.000	120	204 (17.0)	468	414	348	294	258	234
2.250	120	180 (15.0)	462	366	306	264	216	204
2.500	120	162 (13.5)	414	336	276	240	210	186
2.750	120	144 (12.0)	366	300	252	216	186	168
3.000	120	132 (11.0)	348	276	234	198	174	156

①②③④See page 313.

NOTES FOR TABLES 119, 120, 121 122, AND 123

①Sizes greater than indicated may be supplied in some cases, subject to special inquiry.

②LIMITATIONS: The dimensions shown are subject to the following limitations:

(a) The maximum diameters for plate circles are the same as the maximum widths shown, in the as-rolled (-F) and annealed (-O) tempers.

(b) The degree of flatness obtainable varies with the thickness, temper and size of plate. For plate 0.625 inch or more in thickness in the -F temper, the out-of-flatness will approximate ¼ inch in any 6 feet or less; for thinner plate in the -F temper as well as all thicknesses of -O temper, a somewhat greater out-of-flatness can be expected.

(c) Maximum commercial thicknesses, widths or diameters for intermediate tempers of 1100, 3003, 3004, 5050, 5052 and 5154 alloys are as follows:

Thickness, inches	Maximum Commercial Widths or Diameters, inches	
	-H12 or -H32 Tempers	-H14 or -H34 Tempers
2.000–1.500	60	
1.499–1.001	96	
1.000–0.875	96	96
0.874–0.625	125	110
0.624–0.500	102	96
0.499–0.250	96	84

Sizes greater than indicated may be supplied in some cases, subject to special inquiry.

③SHEARED PLATE—Unless otherwise specified on the order, plate is sheared to size within the following limits:

Thickness	Alloys	Minimum Width for Lengths of 168 inches (14 feet)* or less
0.250—0.375	All	6 inch
0.376—0.500	All	8 inch
0.501—1.000	1100, 3003, 3004, 5050, 5052 and 6061	8 inch
1.001—1.250	1100 and 3003	8 inch

*For lengths over 168 inches, the minimum width for shearing is 36 inches.

④PLATE CIRCLES—Plate circles are supplied in diameters from 9 inches to the maximum commercially available. Diameters less than 9 inches and greater than indicated can be supplied in some cases, subject to special inquiry.

TABLE 124

tube (extruded) ROUND

STANDARD MANUFACTURING LIMITS[1]

Outside Diameter, Inches	Minimum Wall Thickness, Inch[3]				Minimum Inside Diameter, Inches	Maximum Over-all Size
	2014, 2024	3003, 6063[5]	6061, 6062	7075		
0.500 to 1.249[2]	....	.050	....	....	Half outside diameter, but in no case under 1 in. for 3003, 6061, 6062 and 6063, or under 2 in. for 2014, 2024 and 7075	12¾ inch outside diameter
1.250 to 2.999	....	.050	.062	....		
3.000 to 3.999	.156	.050	.062	.219		
4.000 to 4.999	.156	.062	.062	.250		
5.000 to 5.999	.188	.062	.078	.281		
6.000 to 6.999	.219	.078	.094	.312		
7.000 to 7.999	.250	.094	.125	.375		
8.000 to 8.999	.281	.125	.156	.438		
9.000 to 9.999	.312	.156	.188	.500		
10.000 to 10.999	.375	.188	.219	....		
11.000 to 12.750	.438	.219	.250	....		

See footnotes below.

TABLE 125

tube (extruded) OTHER THAN ROUND

STANDARD MANUFACTURING LIMITS[1]

Circumscribing Circle Diameter,[4] Inches	Minimum Wall Thickness, Inch[3]		Maximum Over-all Size	Minimum Hole Size
	3003, 6063[5]	6061, 6062		
0.500 to 1.999	.050	.062	5 inch circumscribing circle diameter[4]	0.11 square inch area or 0.375 inch dia.
2.000 to 2.999	.062	.078		
3.000 to 3.999	.078	.094		
4.000 to 5.000	.094	.109		

[1] These Standard Manufacturing Limits do not include the full capabilities of the 14,000-ton extrusion press. Requirements beyond these Standard Manufacturing Limits should be made subject to special inquiry.
[2] Applicable to 6063 alloy only.
[3] Applicable to mean wall thickness if unequal plus and minus tolerances are specified.
[4] The circumscribing circle diameter is the diameter of the smallest circle that will completely enclose the cross section of the tube.
[5] Maximum wall thickness in -T6 temper of 6063 alloy: round tube 0.500 inch; other-than-round tube 0.250 inch.

ABLE
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Tube (drawn)

STANDARD MANUFACTURING LIMITS—SIZE

Alloy and Temper	Round				Other-than-round	
	Outside Diameter,① Inches		Inside Diameter,② Inches		Maximum Circumscribing Circle Diameter,③ Inches	Minimum Hole Size, Square Inch
	Maximum	Minimum	Maximum	Minimum		
024-F	9	1/8	8 3/16	1/8	12	.05
-T3	9	1/8	8 3/16	1/8	12	.05
003-O	10 3/4	1/8	10 3/8	1/8	12	.05
-F	11 1/2	1/8	10 5/8	1/8	12	.05
-H12	11	1/8	10 1/2	1/8	..	...
-H14	11	1/8	10 1/2	1/8	..	...
-H16	10 1/4	1/8	10	1/8	..	...
-H18	10	1/8	9 3/4	1/8	..	...
050-O, 5052-O	4 3/4	1/8	4 1/4	1/8	12	.05
061-O, 6062-O	10 3/4	1/8	10 3/8	1/8	12	.05
-F, 6062-F	11 1/2	1/8	10 5/8	1/8	12	.05
-T4, 6062-T4	11 1/4	1/8	10 13/32	1/8	12	.05
-T6, 6062-T6	11 1/4	1/8	10 13/32	1/8	12	.05
063-T83, 6063-T831	6 1/4	3/8	6 1/16	1/4	..	...
-T832	6 1/4	3/8	6 1/16	1/4	..	...

① Where tubes are specified by outside diameter and wall thickness.
② Where tubes are specified by outside and inside diameter, or by inside diameter and wall thickness.
③ The circumscribing circle diameter is the diameter of the smallest circle that will completely enclose the cross-section of the tube.

TABLE 127 Tube (drawn) Round

STANDARD MANUFACTURING LIMITS—WALL THICKNESSES①

Outside Diameter,② Inches	Minimum Wall Thickness, Inch		Maximum Wall Thickness, Inch					
			Where Tube is Specified by Outside Diameter and Wall Thickness					Specified by OD & ID or ID & Wall
	6061 6062	6063	6061-O 6062-O	6061-F 6062-F	6061-T4 6061-T6 6062-T4 6062-T6	6063-T83 6063-T831	6063-T832	All Alloys
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1/8	.014	....	.049	.049	.049	....	....	....
3/16	.014	....	.078	.078	.078	....	....	.028
1/4	.014	....	.109	.109	.109	....	....	.058
5/16	.014	....	.134	.134	.134	....	....	.083
3/8	.016	.065	.148	.148	.148	.072	.072	.120③
7/16	.018	.058	.165	.165	.165	.072	.072	.148③
1/2	.018	.049	.180	.180	.180	.078	.078	.148③
5/8	.018	.042	.238	.238	.238	.109	.100	.203③
3/4	.018	.031	.259	.259	.259	.125	.100	.238③
7/8	.018	.028	.300	.300	.300	.148	.100	.284③
1	.020	.028	.320	.320	.320	.148	.100	.284③
1 1/8	.020	.028	.320	.320	.320	.148	.100	.320③
1 1/4	.020	.028	.320	.320	.320	.250	.172	.320③
1 3/8	.020	.028	.375	.375	.375	.250	.172	.375③
1 1/2	.020	.028	.450	.450	.450	.250	.172	.400③
1 5/8	.020	.028	.450	.450	.450	.250	.172	.400③
1 3/4	.020	.028	.450	.450	.450	.250	.172	.400③
1 7/8	.020	.028	.450	.450	.450	.250	.172	.400③
2	.022	.035	.450	.450	.450	.200	.148	.400③
2 1/4	.022	.035	.450	.450	.450	.125	.093	.400③

See footnotes page 318.

TABLE 127

Tube (drawn) ROUND

STANDARD MANUFACTURING LIMITS—WALL THICKNESSES[1]—*Continued*

Outside Diameter,[2] Inches	Minimum Wall Thickness, Inch		Maximum Wall Thickness, Inch					
			Where Tube is Specified by Outside Diameter and Wall Thickness					Specified by OD & ID or ID & Wall
	6061 6062	6063	6061-O 6062-O	6061-F 6062-F	6061-T4 6061-T6 6062-T4 6062-T6	6063-T83 6063-T831	6063-T832	All Alloys
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
2½	.022	.035	.450	.450	.450	.109	.093	.400[3]
2¾	.022	.062	.500	.500	.500	.125	.093	.400[3]
3	.028	.062	.500	.500	.500	.125	.093	.400[3]
4	.042	.058	.500	.500	.500	.125	.093	.400[3]
4¼	.042	.072	.500	.500	.500	.125	.100	.400[3]
4½	.042	072	.500	.500	.500	.125	100	400[3]
4¾	.042	.065	.500	500	.500	.125	100	400[3]
5	.042	.078	.500	.500	.500	.125	.093	.400[3]
5¼	.042	.072	.500	.500	.500	125	125	.400[3]
5½	.042	.072	.500	.500	.500	.140	120	400[3]
5¾	.049	.072	.500	.500	.500	.150	.109	400[3]
6	.049	.072	.500	.500	.500	.150	.109	.400[3]
6¼	.049	.087	.500	500	.500	.165	.109	.400[3]
6½	.058	....	.500	.500	.500	....	....	.400
6¾	.058	....	.500	.500	.500	....	....	.400
7	.062	....	.500	.500	.500	....	....	.437
7¼	.062	....	.500	.500	.500	....	....	.437
7½	.062	....	.484	.500	.500	....	....	.437
7¾	.078	....	.468	.500	.500	....	....	.437

See page 318 for footnotes.

TABLE 127 Tube (drawn)

STANDARD MANUFACTURING LIMITS—WALL THICKNESSES[1]—*Concluded*

Outside Diameter,[2] Inches	Minimum Wall Thickness, Inch		Maximum Wall Thickness, Inch					
			Where Tube is Specified by Outside Diameter and Wall Thickness					Specified by OD & ID or ID & Wall
	6061 6062	6063	6061-O 6062-O	6061-F 6062-F	6061-T4 6061-T6 6062-T4 6062-T6	6063-T83 6063-T831	6063-T832	All Alloys
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
8	.078	....	.453	.500	.500	....	....	.437
8¼	.078	....	.437	.500	.500	....	....	.437
8½	.078	....	.421	.500	.500	....	....	.437[3]
8¾	.078	....	.406	.500	.500	....	....	.437[3]
9	.093	....	.390	.500	.500	....	....	.437[3]
9¼	.093	....	.375	.500	.500	....	....	.437[3]
9½	.109	....	.375	.500	.500	....	....	.437[3]
9¾	.125	....	.359	.500	.484	....	....	.437[3]
10	.125	....	.344	.500	.468	....	....	.437[3]
10¼	.125	....	.344	.500	.453	....	....	.437[3]
10½	.156	....	.328	.500	.453	....	....	.437[3]
10¾	.187	....	.312	.500	.453	....	....	.437[3]
11	.250	....	....	.500	.421	....	....	.437[3]
11¼	.312	....	....	.500	.421	....	....	.437[3]
11½	.437	....	....	.500	....	....	....	.437

[1] Standard wall thickness limits of other-than-round tube are the same as those of round tube of the same perimeter.
[2] Range, up to but not including the next larger outside diameter shown.
[3] Or the thickness shown in Cols. 4 to 8, incl., for the alloy and temper in question, whichever is less.

TABLE 28

structural shapes (standard)

COMMERCIAL SIZES

Alloy: 6061

ANGLES		STRUCTURAL CHANNELS	TEES
Size, Inches	Size, Inches	Depth, Inches	Size, Inches Flange Stem
¾ x ¾	3½ x 2½	3	2 x 2
	3½ x 3	4	2¼ x 2¼
	3½ x 3½	5	2½ x 2½
1 x 1		6	3 x 3
1¼ x ¾		7	
1¼ x 1		8	4 x 4
1¼ x 1¼	4 x 3	9	
1½ x ¾	4 x 3½	10	ZEES
1½ x 1	4 x 4	12	Depth, Inches
1½ x 1¼		15	3
1½ x 1½			4
1¾ x 1¼	5 x 3	SPECIAL CHANNELS	4 1/16
1¾ x 1¾	5 x 3½		4⅛
	5 x 5	3 6	5
2 x 1½		4 8	
2 x 2		5 10	WIDE-FLANGE SECTIONS
2½ x 1½	6 x 3½		4
2½ x 2	6 x 4	I-BEAMS	5
2½ x 2½	6 x 6	3 7	6
		4 8	8
3 x 2		5 10	9.9
3 x 2½	8 x 6	6 12	
3 x 3	8 x 8		

Many of the above sections are obtainable in several different flange, web or stem thicknesses. Consult nearest Alcoa sales office.

Elements of sections are given in Tables 40 through 60, on pages 212 through 273.

Above list includes both extruded and rolled shapes.

Maximum length in a heat-treated alloy—Smaller sizes, 50 feet
—Larger sizes, 85 feet.

TABLE 129

COMMERCIAL SIZE RANGE

Alloys: 1100, 3003, 5052, 5056

Thickness, Inch	Width, Inch
0.187 to 0.125	0.189 to 1.000
0.124 to 0.098	0.125 to 1.000
0.097 to 0.020①	0.063 to 1.000

①Maximum ratio of width to thickness for thicknesses .020 to .042 is 10 to 1.

TABLE 130

COMMERCIAL SIZE RANGE①

COMMODITY	SMALLEST	LARGEST
	Diameter, Inches	Diameter, Inches
Round Wire—Drawn	0.010	0.374
Round Rod—Cold-Finished	3/8	3
Round Rod—Rolled	1 9/16	8
	Distance Across Flats, Inches	Distance Across Flats, Inches
Square Wire—Drawn	1/8 x 1/8	11/32 x 11/32
Square Bar—Cold-Finished	3/8 x 3/8	1 1/2 x 1 1/2
Square Bar—Rolled	1 5/8 x 1 5/8	4 x 4
Hexagonal Wire—Drawn	3/16	11/32
Hexagonal Bar—Cold-Finished	3/8	2
Hexagonal Bar—Rolled	1 9/16	3
	Dimensions, Inch	Dimensions, Inches
Square Edge Rectangular Wire—Drawn	1/32 x 1/8	5/16 x 11/32
Square Edge Rectangular Bar—Cold-Finished	1/8 x 3/8	1 1/2 x 4
Square Edge Rectangular Bar—Rolled	3/16 x 3/4	3 x 7
Round Edge Rectangular Bar—Rolled	3/16 x 3/4	1/2 x 6

①This table indicates the range of commercial sizes. All alloys are not produced in all of the sizes listed; consult the sales representative of Aluminum Company of America for details.

CONVERSION TABLES AND OTHER USEFUL DATA

TABLE 131

Weight of Aluminum Sheet and Plate

(Alloys 1100, 3004, 6061)[1] [2]

Nominal Weight—Pounds per Lineal Foot

Thickness, Inches	Width in Inches											
	1	2	3	4	5	6	7	8	9	10	11	12
0.008	0.009	0.019	0.028	0.037	0.047	0.056	0 066	0.075	0.085	0.094	0.103	0.113
0.010	0.012	0 023	0.035	0.047	0.059	0 070	0 082	0.094	0.105	0.117	0.129	0.141
0.012	0.014	0 028	0.042	0.056	0 070	0 085	0 098	0.113	0.127	0.141	0.155	0.169
0.016	0.019	0 038	0 056	0.075	0 094	0 113	0 132	0.150	0.169	0.188	0.208	0.226
0.020	0.024	0 047	0 071	0.094	0 117	0.141	0 164	0.188	0.212	0.235	0.259	0.282
0.025	0.029	0.059	0.088	0.118	0 147	0 176	0 205	0.235	0.265	0.294	0.323	0.353
0.032	0.038	0.075	0.113	0.150	0 188	0 226	0 264	0.301	0.338	0.376	0.414	0.452
0.040	0.047	0.094	0 141	0.188	0 235	0 282	0.329	0.376	0.423	0.470	0.517	0.565
0.051	0.060	0.120	0 180	0.240	0 300	0 360	0 419	0 479	0.539	0.599	0.659	0.720
0.064	0.075	0 150	0.226	0.301	0 376	0 452	0 526	0.601	0.677	0.752	0.827	0.904
0.072	0.085	0.169	0.254	0.338	0.423	0 508	0 592	0.677	0.761	0.846	0.931	1.02
0.081	0.095	0.190	0.286	0.381	0 476	0 571	0 666	0.762	0.856	0.952	1.05	1.14
0.091	0.107	0.214	0.321	0.428	0 535	0 642	0 750	0.857	0.964	1.07	1.18	1.28
0.102	0.120	0.240	0 360	0.480	0.600	0.719	0.840	0.959	1.08	1.19	1.31	1.44
0.125	0.147	0.294	0 441	0.588	0.735	0 882	1.03	1.18	1.99	1.47	1.62	1.76
0.188	0.221	0.442	0.663	0.884	1 11	1.33	1.55	1.77	1.99	2.21	2.43	2.65
0.250	0.294	0.587	0.880	1.17	1 47	1.76	2.05	2.34	2.64	2.94	3.23	3.53
0.375	0.441	0.882	1 32	1.76	2 21	2 65	3.08	3.52	3.97	4.41	4.85	5.29
0.500	0.588	1.18	1 76	2.35	2 94	3.53	4.12	4.69	5.29	5.88	6.47	7.06
0.750	0.881	1.76	2 64	3.52	4 41	5.29	6.17	7.04	7.93	8.81	9.69	10.58
1.000	1.18	2.35	3.53	4.70	5 88	7.05	8.23	9.40	10.58	11.75	12.92	14.11
1.250	1.47	2.94	4.41	5.88	7 35	8.82	10.28	11.75	13.22	14.69	16.16	17.64
1.500	1.76	3.53	5.29	7.05	8.81	10.58	12.34	14.10	15.86	17.62	19.38	21.17
2.000	2.35	4 70	7.05	9 40	11.75	14.11	16.44	18.80	21.15	23.50	25.85	28.22
2.500	2.94	5.87	8.80	11.74	14.68	17.64	20.52	23.48	26.42	29.35	32.29	35.28
3.000	3.53	7.05	10.58	14.10	17.63	21.16	24.65	28.20	31.73	35.25	38.78	42.33

[1] For weights in other alloys, multiply by: 2014–1.03, 3003–1.01, 5052–0.99, 2024–1.02, 5050–0.99, 7075–1.03.

[2] These weights assume a complete lack of "crown" in the sheet or plate.

TABLE
132

Lengths of Aluminum Rivets for Various Grips

Hole diameter not more than 1/32 inch greater than rivet diameter.

LENGTHS OF RIVETS FOR CONE-POINT DRIVEN HEADS

Grip	d=1/4	d=5/16	d=3/8	d=1/2	d=5/8	d=3/4	d=7/8	d=1
1/8	7/16	1/2	9/16	11/16	13/16	1	1 1/8	1 1/4
1/4	5/8	5/8	11/16	13/16	15/16	1 1/8	1 1/4	1 3/8
3/8	13/16	13/16	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
1/2	15/16	1	1	1 1/8	1 5/16	1 3/8	1 1/2	1 5/8
5/8	1 1/8	1 1/8	1 3/16	1 1/4	1 7/16	1 1/2	1 5/8	1 3/4
3/4	1 1/4	1 5/16	1 5/16	1 3/8	1 9/16	1 11/16	1 3/4	1 7/8
7/8	1 7/16	1 1/2	1 1/2	1 9/16	1 11/16	1 13/16	1 15/16	2
1	1 5/8	1 5/8	1 5/8	1 11/16	1 13/16	1 15/16	2 1/16	2 1/8
1 1/8	...	1 3/4	1 13/16	1 7/8	2	2 1/8	2 3/16	2 5/16
1 1/4	...	2	2	2	2 1/8	2 1/4	2 3/8	2 1/2
1 3/8	...	...	2 1/8	2 3/16	2 1/4	2 3/8	2 1/2	2 5/8
1 1/2	...	...	2 1/4	2 5/16	2 7/16	2 9/16	2 5/8	2 3/4
1 5/8	...	...	...	2 7/16	2 9/16	2 11/16	2 3/4	2 7/8
1 3/4	...	...	...	2 5/8	2 11/16	2 13/16	2 15/16	3 1/16
1 7/8	...	...	...	2 3/4	2 7/8	2 15/16	3 1/16	3 3/16
2	...	...	...	2 15/16	3	3 1/8	3 3/16	3 5/16
2 1/8	...	...	...	...	3 1/8	3 1/4	3 5/16	3 1/2
2 1/4	...	...	...	...	3 5/16	3 7/16	3 1/2	3 5/8
2 3/8	...	...	...	...	3 7/16	3 9/16	3 5/8	3 3/4
2 1/2	...	...	...	...	3 9/16	3 11/16	3 3/4	3 7/8

LENGTHS OF RIVETS FOR BUTTON DRIVEN HEADS

Grip	d=1/4	d=5/16	d=3/8	d=1/2	d=5/8	d=3/4	d=7/8	d=1
1/8	9/16	5/8	3/4	...	...	...	...	...
1/4	3/4	13/16	7/8	1	1 1/16	1 3/8	...	...
3/8	15/16	15/16	1 1/16	1 3/16	1 3/8	1 1/2	1 5/8	1 3/4
1/2	1 1/16	1 1/8	1 3/16	1 5/16	1 1/2	1 5/8	1 3/4	1 7/8
5/8	1 3/16	1 1/4	1 5/16	1 1/2	1 11/16	1 3/4	1 7/8	2
3/4	1 3/8	1 7/16	1 1/2	1 5/8	1 13/16	1 15/16	2	2 1/8
7/8	1 1/2	1 5/8	1 11/16	1 13/16	1 15/16	2 1/16	2 1/8	2 1/4
1	1 3/4	1 3/4	1 13/16	1 15/16	2 1/16	2 3/16	2 1/4	2 3/8
1 1/8	...	1 15/16	2	2 1/8	2 3/16	2 3/8	2 3/8	2 1/2
1 1/4	...	2 1/8	2 1/8	2 1/4	2 3/8	2 1/2	2 1/2	2 5/8
1 3/8	...	...	2 5/16	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8
1 1/2	...	...	2 1/2	2 1/2	2 11/16	2 13/16	2 7/8	3
1 5/8	...	...	...	2 11/16	2 13/16	2 15/16	3	3 1/8
1 3/4	...	...	...	2 7/8	2 15/16	3 1/8	3 1/8	3 1/4
1 7/8	...	...	...	3	3 1/8	3 1/4	3 1/4	3 3/8
2	...	...	...	3 3/16	3 1/4	3 3/8	3 3/8	3 1/2
2 1/8	...	...	...	...	3 7/16	3 1/2	3 1/2	3 5/8
2 1/4	...	...	...	...	3 9/16	3 5/8	3 5/8	3 3/4
2 3/8	...	...	...	...	3 3/4	3 3/4	3 3/4	3 7/8
2 1/2	...	...	...	...	3 7/8	3 7/8	3 7/8	4

TABLE
133

Weights of Structural Aluminum Rivets

BUTTON HEAD

Weights given are for 2017

For 2117 multiply by 0.980. For 6061 multiply by 0.970

VALUES GIVEN IN POUNDS PER HUNDRED RIVETS

Length under head, Inches	Diameter in inches										
	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
Weight of heads only →	0.2	0.4	0.6	0.9	1.4	2.8	4.8	7.6	11.3	16.1	22.1
1/2	0.4	...	...	...	...	..	..	..	..	..	..
5/8	0.5	0.9	...	...	...	..	..	..	..	..	..
3/4	0.6	1.0	1.4	..	...	..	..	..	..	..	..
7/8	0.6	1.1	1.6	2.2	..	..	..	..	..	..	..
1	0.7	1.2	1.7	2.4	3.4	..	..	..	..	..	..
1 1/8	0.8	1.3	1.9	2.6	3.6	..	..	..	..	..	..
1 1/4	0.8	1.4	2.0	2.8	3.9	7	..	..	..	..	..
1 3/8	0.9	1.5	2.1	3.0	4.1	7	..	..	..	..	..
1 1/2	0.9	1.6	2.3	3.2	4.4	7	12	..	..	..	..
1 5/8	1.0	1.7	2.4	3.4	4.6	8	12	..	..	..	..
1 3/4	1.1	1.8	2.6	3.6	4.9	8	13	18	..	..	..
1 7/8	1.1	1.9	2.7	3.8	5.1	9	13	19	..	..	..
2	1.2	2.0	2.8	3.9	5.4	9	14	20	27	..	..
2 1/8	1.2	2.0	3.0	4.1	5.6	9	14	21	28	..	..
2 1/4	1.3	2.1	3.1	4.3	5.9	10	15	21	29	39	..
2 3/8	1.4	2.2	3.3	4.5	6.1	10	15	22	30	40	..
2 1/2	1.4	2.3	3.4	4.7	6.4	11	16	23	31	41	53
2 5/8	1.5	2.4	3.5	4.9	6.6	11	17	24	32	42	55
2 3/4	1.6	2.5	3.7	5.1	6.9	11	17	24	33	44	56
2 7/8	1.6	2.6	3.8	5.3	7.1	12	18	25	34	45	58
3	1.7	2.7	3.9	5.5	7.3	12	18	26	35	46	59
3 1/8	1.7	2.8	4.1	5.7	7.6	13	19	27	36	47	61
3 1/4	1.8	2.9	4.2	5.8	7.8	13	19	27	37	49	62
3 3/8	1.9	3.0	4.4	6.0	8.1	13	20	28	38	50	64
3 1/2	1.9	3.1	4.5	6.2	8.3	14	20	29	39	51	65
3 5/8	2.0	3.2	4.6	6.4	8.6	14	21	30	40	52	67
3 3/4	2.0	3.3	4.8	6.6	8.8	14	22	30	41	54	69
3 7/8	2.1	3.4	4.9	6.8	9.1	15	22	31	42	55	70
4	2.2	3.5	5.1	7.0	9.3	15	23	32	43	56	72
4 1/8	2.2	3.6	5.2	7.2	9.6	16	23	33	44	58	73
4 1/4	2.3	3.7	5.3	7.4	9.8	16	24	33	45	59	75
4 3/8	2.4	3.8	5.5	7.6	10.1	16	24	34	46	60	76
4 1/2	2.4	3.9	5.6	7.7	10.3	17	25	35	47	61	78
4 5/8	2.5	4.0	5.8	7.9	10.6	17	25	36	48	63	79
4 3/4	2.5	4.1	5.9	8.1	10.8	18	26	36	49	64	81
4 7/8	2.6	4.2	6.0	8.3	11.1	18	27	37	50	65	82
5	2.7	4.3	6.2	8.5	11.3	18	27	38	51	66	84

TABLE
134

Weight of Regular Hexagon Head Machine Bolts

Alloy 2024-T4

APPROXIMATE WEIGHT PER 1000 PIECES (LBS)

Length L, inches	THREAD SIZE					
	1/4–20	5/16–18	3/8–16	1/2–13	5/8–11	3/4–10
1/2	4.48	7.45	10.9	....	....	.....
5/8	4.94	8.21	12.0	....	....	.....
3/4	5.41	8.96	13.1	27.4	....	.....
7/8	5.88	9.71	14.2	29.4	....	.....
1	6.34	10.5	15.3	31.4	55.4	.....
1 1/4	7.83	12.6	17.5	35.4	61.7	98.3
1 1/2	9.03	14.5	20.8	39.4	68.0	108.
1 3/4	10.2	16.3	23.5	45.2	74.4	117.
2	11.5	18.2	26.2	50.0	83.1	126.
2 1/4	12.7	20.1	28.9	54.9	90.7	139.
2 1/2	13.9	22.0	31.7	59.8	98.2	150.
2 3/4	15.1	23.9	34.4	64.6	106.	161.
3	16.3	25.8	37.1	69.5	113.	171.
3 1/4	17.5	27.7	39.8	74.4	121.	182.
3 1/2	18.7	29.6	42.6	79.3	128.	193.
3 3/4	19.9	31.5	45.3	84.1	136.	204.
4	21.2	33.4	48.0	89.0	143.	215.
4 1/2	23.5	37.2	53.5	98.7	159.	237.
5	26.0	40.9	58.9	109.	174.	259.
5 1/2	28.4	44.7	64.4	118.	189.	280.
6	30.8	48.5	69.8	128.	204.	302.

① Weights given are for coarse thread series. Bolts in the fine thread series will be slightly heavier.

② For design purposes, weights of Economy and Finished Hexagon Head Bolts, in corresponding sizes, are abou the same as given above.

TABLE 135

Weight of Aluminum Hexagon Finished Bolt Nuts[1]

APPROXIMATE WEIGHT PER 1000 PIECES (LBS)

Type of Nut	Nominal Size, in.					
	1/4 - 20	5/16 - 18	3/8 - 16	1/2 - 13	5/8 - 11	3/4 - 10
Hexagon Finished	2.81	4.14	6.10	14.3	27.9	46.6

[1]The 1/4"—20 size nuts are alloy 2024-T4. All other sizes of nuts are alloy 6061-T6.

TABLE 136

Alcoa Alloy Designations for Wrought Aluminum Products[1] as Adopted October 1, 1954

CONVERSION CHART

Old Alloy Designation	New Alloy Designation[2]	Old Alloy Designation	New Alloy Designation[2]	New Alloy Designation[2]	Old Alloy Designation	New Alloy Designation[2]	Old Alloy Designation
99.3[3]	1230	18S	2018	EC[5]	EC	X2316	XC16S
99.6, CD1S	1160	B18S	2218	1030	AE1S	2618	F18S
99.75[4]	1175	F18S	2618	1050	AD1S	3003	3S
99.87, EB1S	1187	24S	2024	1060	BD1S	3004	4S
EC[5]	EC	25S	2025	1070	AC1S	X3005	XA5S
AA1S	1095	B25S	2225	1075	JC1S	4032	32S
BA1S	1099	32S	4032	1080	BC1S	4043	43S
CA1S	1197	43S	4043	1085	AB1S	X4543	XE43S
AB1S	1085	XE43S	X4543	1090	FB1S	5005	A50S
EB1S, 99.87	1187	50S	5050	1095	AA1S	5050	50S
FB1S	1090	A50S	5005	1099	BA1S	5052	52S
AC1S	1070	XD50S	X5405	1100	2S	5056	56S
BC1S	1080	A51S	6151	1145	BE1S	5154	A54S
CC1S	1180	J51S	6951	1150	ED1S	5254	B54S
JC1S	1075	52S	5052	1160	CD1S, 99.6	X5356	XC56S
AD1S	1050	F52S	5652	1170	FC1S	5357	C57S
BD1S	1060	53S	6053	1175[4]	99.75	X5405	XD50S
CD1S, 99.6	1160	B53S	6253	1180	CC1S	5652	F52S
ED1S	1150	E53S	6553	1187	EB1S, 99.87	6053	53S
AE1S	1030	A54S	5154	1197	CA1S	6061	61S
BE1S	1145	B54S	5254	1230[3]	99.3	6062	62S
FC1S	1170	56S	5056	2011	11S	6063	63S
2S	1100	XC56S	X5356	2014	14S	6151	A51S
3S	3003	C57S	5357	2017	17S	6253	B53S
4S	3004	61S	6061	2018	18S	6553	E53S
XA5S	X3005	62S	6062	2024	24S	6951	J51S
11S	2011	63S	6063	2025	25S	7070	70S
14S	2014	70S	7070	2117	A17S	7072	72S
XB14S	X2214	72S	7072	X2214	XB14S	7075	75S
XC16S	X2316	75S	7075	2218	B18S	X7178	XA78S
17S	2017	B77S	7277	2225	B25S	7277	B77S
A17S	2117	XA78S	X7178			X8280	XB80S
		XB80S	X8280				

[1] The present temper designation system in effect since December 31, 1947 is continued without change. The temper designation follows the alloy designation and is separated from it by a dash. 3S-O is now 3003-O, 75S-T6 is 7075-T6. Alclad 24S-T81 is Alclad 2024-T81.

[2] Effective on orders entered October 1, 1954 and later.

[3] Cladding on Alclad 2024.

[4] Cladding on No. 2 Reflector Sheet.

[5] EC—The designation for electrical conductor metal is not being changed since it is so firmly established in the electrical industry.

TABLE 137

Approximate Properties of Common Metals[1]

Material	Weight, Lb/Cu Ft	Modulus of Elasticity, Kips Per Sq In.	Poisson's Ratio	Coefficient[2] of Expansion, In./In./°F	Specific Heat, Cal/G	Conductivity	
						Thermal[3]	Electrical[4]
Aluminum[5]	169	10,000	0.33	0.000013	0.215	0.53	58
Magnesium[5]	109	6,500	0.35	0.000015	0.249	0.38	39
Titanium[5]	283	16,800	....	0.000005	0.126	....	2
Yellow Brass	529	15,000	0.33	0.000011	0.09	0.28	27
Copper[5]	560	16,000	0.33	0.000009	0.092	0.94	103
Malleable Iron	456	25,000	0.17	0.000007	0.122	....	.
Lead[5]	708	2,600	0.43	0.000016	0.031	0.08	8
Monel Metal	551	26,000	0.39	0.000008	0.127	0.06	4
Plain Carbon Steel	490	29,000	0.28	0.000007	0.117	0.12	13
Zinc[5]	446	.....	0.11	0.000022	0.092	0.27	28

[1] For other metals and alloys see Metals Handbook, 1948 Edition, ASM.
[2] For temperatures between 68°—212°F.
[3] Calories transmitted per second through a plate one centimeter thick per square centimeter of its surface, for a temperature differential between the two faces of the plate of 1°C.
[4] Volume conductivity at 20°C in per cent based on International Annealed Copper Standard.
[5] Pure or commercially pure.

TABLE 138

Fractions to Decimals

Fractions	Decimals	Fractions	Decimals
1/64	0.015625	33/64	0.515625
1/32	0.03125	17/32	0.53125
3/64	0.046875	35/64	0.546875
1/16	0.0625	9/16	0.5625
5/64	0.078125	37/64	0.578125
3/32	0.09375	19/32	0.59375
7/64	0.109375	39/64	0.609375
1/8	0.125	5/8	0.625
9/64	0.140625	41/64	0.640625
5/32	0.15625	21/32	0.65625
11/64	0.171875	43/64	0.671875
3/16	0.1875	11/16	0.6875
13/64	0.203125	45/64	0.703125
7/32	0.21875	23/32	0.71875
15/64	0.234375	47/64	0.734375
1/4	0.25	3/4	0.75
17/64	0.265625	49/64	0.765625
9/32	0.28125	25/32	0.78125
19/64	0.296875	51/64	0.796875
5/16	0.3125	13/16	0.8125
21/64	0.328125	53/64	0.828125
11/32	0.34375	27/32	0.84375
23/64	0.359375	55/64	0.859375
3/8	0.375	7/8	0.875
25/64	0.390625	57/64	0.890625
13/32	0.40625	29/32	0.90625
27/64	0.421875	59/64	0.921875
7/16	0.4375	15/16	0.9375
29/64	0.453125	61/64	0.953125
15/32	0.46875	31/32	0.96875
31/64	0.484375	63/64	0.984375
1/2	0.5	1	1.0

TABLE 139

Useful Conversion Factors

One board foot	= 144	cubic inches
One centimeter	= 0.3937	inch
One centimeter	= 0.01	meter
One centimeter	= 10	millimeters
One cubic centimeter	= 3.531×10^{-5}	cubic feet
One cubic centimeter	= 0.06102	cubic inch
One cubic foot	= 28317	cubic centimeters
One cubic foot	= 1728	cubic inches
One cubic foot	= 7.481	gallons
One cubic foot	= 28.32	liters
One cubic inch	= 16.39	cubic centimeters
One degree (angle)	= 0.01745	radian
One foot per second	= 0.6818	mile per hour
One gallon	= 231	cubic inches
One gallon	= 3.785	liters
One gram	= 2.205×10^{-3}	pounds
One gram per cc	= 62.43	pounds per cubic foot
One horsepower	= 550	foot-pounds per second
One horsepower	= 0.7457	kilowatt
One inch	= 2.540	centimeters
One kilogram	= 1000	grams
One kilogram	= 2.205	pounds
One kg per sq mm	= 1422	pounds per square inch
One kip	= 1000	pounds
One mile	= 5280	feet
One pound	= 453.6	grams
One lb per sq in.	= 0.068	atmosphere
One lb per sq in.	= 2.307	feet of water
One lb per sq in.	= 2.036	inches of mercury
One lb per sq in.	= 7.031×10^{-4}	kg per sq mm
One radian	= 57.30	degrees
One square inch	= 6.452	square centimeters
One ton (short)	= 2000	pounds
One ton (metric)	= 2205	pounds
One ton (long)	= 2240	pounds
One ton (long) per sq in.	= 1.575	kg per sq mm

TABLE 140

Inches to Decimals of a Foot

Fractions of an Inch	Decimals of a Foot											
	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
0	0.0000	0.0833	0.1667	0.2500	0.3333	0.4167	0.5000	0.5833	0.6667	0.7500	0.8333	0.9167
1/16	0.0052	0.0885	0.1719	0.2552	0.3385	0.4219	0.5052	0.5885	0.6719	0.7552	0.8385	0.9219
1/8	0.0104	0.0938	0.1771	0.2604	0.3438	0.4271	0.5104	0.5938	0.6771	0.7604	0.8438	0.9271
3/16	0.0156	0.0990	0.1823	0.2656	0.3490	0.4323	0.5156	0.5990	0.6823	0.7656	0.8490	0.9323
1/4	0.0208	0.1042	0.1875	0.2708	0.3542	0.4375	0.5208	0.6042	0.6875	0.7708	0.8542	0.9375
5/16	0.0260	0.1094	0.1927	0.2760	0.3594	0.4427	0.5260	0.6094	0.6927	0.7760	0.8594	0.9427
3/8	0.0313	0.1146	0.1979	0.2813	0.3646	0.4479	0.5313	0.6146	0.6979	0.7813	0.8646	0.9479
7/16	0.0365	0.1198	0.2031	0.2865	0.3698	0.4531	0.5365	0.6198	0.7031	0.7865	0.8698	0.9531
1/2	0.0417	0.1250	0.2083	0.2917	0.3750	0.4583	0.5417	0.6250	0.7083	0.7917	0.8750	0.9583
9/16	0.0469	0.1302	0.2135	0.2969	0.3802	0.4635	0.5469	0.6302	0.7135	0.7969	0.8802	0.9635
5/8	0.0521	0.1354	0.2188	0.3021	0.3854	0.4688	0.5521	0.6354	0.7188	0.8021	0.8854	0.9688
11/16	0.0573	0.1406	0.2240	0.3073	0.3906	0.4740	0.5573	0.6406	0.7240	0.8073	0.8906	0.9740
3/4	0.0625	0.1458	0.2292	0.3125	0.3958	0.4792	0.5625	0.6458	0.7292	0.8125	0.8958	0.9792
13/16	0.0677	0.1510	0.2344	0.3177	0.4010	0.4844	0.5677	0.6510	0.7344	0.8177	0.9010	0.9844
7/8	0.0729	0.1563	0.2396	0.3229	0.4063	0.4896	0.5729	0.6563	0.7396	0.8229	0.9063	0.9896
15/16	0.0781	0.1615	0.2448	0.3281	0.4115	0.4948	0.5781	0.6615	0.7448	0.8281	0.9115	0.9948

TABLE 141

Inches to Centimeters

(One Foot = 30.480 Centimeters)

Fractions of an Inch	Centimeters											
	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
0	0.000	2.540	5.080	7.620	10.160	12.700	15.240	17.780	20.320	22.860	25.400	27.940
1/32	0.079	2.619	5.159	7.699	10.239	12.779	15.319	17.859	20.399	22.939	25.479	28.019
1/16	0.159	2.699	5.239	7.779	10.319	12.859	15.399	17.939	20.479	23.019	25.559	28.099
3/32	0.238	2.778	5.318	7.858	10.398	12.938	15.478	18.018	20.558	23.098	25.638	28.178
1/8	0.318	2.858	5.398	7.938	10.478	13.018	15.558	18.098	20.638	23.178	25.718	28.258
5/32	0.397	2.937	5.477	8.017	10.557	13.097	15.637	18.177	20.717	23.257	25.797	28.337
3/16	0.476	3.016	5.556	8.096	10.636	13.176	15.716	18.256	20.796	23.336	25.876	28.416
7/32	0.556	3.096	5.636	8.176	10.716	13.256	15.796	18.336	20.876	23.416	25.956	28.496
1/4	0.635	3.175	5.715	8.255	10.795	13.335	15.875	18.415	20.955	23.495	26.035	28.575
9/32	0.714	3.254	5.794	8.334	10.874	13.414	15.954	18.494	21.034	23.574	26.114	28.654
5/16	0.794	3.334	5.874	8.414	10.954	13.494	16.034	18.574	21.114	23.654	26.194	28.734
11/32	0.873	3.413	5.953	8.493	11.033	13.573	16.113	18.653	21.193	23.733	26.273	28.813
3/8	0.953	3.493	6.033	8.573	11.113	13.653	16.193	18.733	21.273	23.813	26.353	28.893
13/32	1.032	3.572	6.112	8.652	11.192	13.732	16.272	18.812	21.352	23.892	26.432	28.972
7/16	1.111	3.651	6.191	8.731	11.271	13.811	16.351	18.891	21.431	23.971	26.511	29.051
15/32	1.191	3.731	6.271	8.811	11.351	13.891	16.431	18.971	21.511	24.051	26.591	29.131
1/2	1.270	3.810	6.350	8.890	11.430	13.970	16.510	19.050	21.590	24.130	26.670	29.210
17/32	1.349	3.889	6.429	8.969	11.509	14.049	16.589	19.129	21.669	24.209	26.749	29.289
9/16	1.429	3.969	6.509	9.049	11.589	14.129	16.669	19.209	21.749	24.289	26.829	29.369
19/32	1.508	4.048	6.588	9.128	11.668	14.208	16.748	19.288	21.828	24.368	26.908	29.448
5/8	1.588	4.128	6.668	9.208	11.748	14.288	16.828	19.368	21.908	24.448	26.988	29.528
21/32	1.667	4.207	6.747	9.287	11.827	14.367	16.907	19.447	21.987	24.527	27.067	29.607
11/16	1.746	4.286	6.826	9.366	11.906	14.446	16.986	19.526	22.066	24.606	27.146	29.686
23/32	1.826	4.366	6.906	9.446	11.986	14.526	17.066	19.606	22.146	24.686	27.226	29.766
3/4	1.905	4.445	6.985	9.525	12.065	14.605	17.145	19.685	22.225	24.765	27.305	29.845
25/32	1.984	4.524	7.064	9.604	12.144	14.684	17.224	19.764	22.304	24.844	27.384	29.924
13/16	2.064	4.604	7.144	9.684	12.224	14.764	17.304	19.844	22.384	24.924	27.464	30.004
27/32	2.143	4.683	7.223	9.763	12.303	14.843	17.383	19.923	22.463	25.003	27.543	30.083
7/8	2.223	4.763	7.303	9.843	12.383	14.923	17.463	20.003	22.543	25.083	27.623	30.163
29/32	2.302	4.842	7.382	9.922	12.462	15.002	17.542	20.082	22.622	25.162	27.702	30.242
15/16	2.381	4.921	7.461	10.001	12.541	15.081	17.621	20.161	22.701	25.241	27.781	30.321
31/32	2.461	5.001	7.541	10.081	12.621	15.161	17.701	20.241	22.781	25.321	27.861	30.401

TABLE
142

Recommended Structural Designations for Use on Drawings

Group	Example
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I-beams	4 I 2.64
Channels	5 ⌴ 2.32
Wide-flange sections	8 WF 10.72
Tees	T 3x3x2.72
Zees	Z 4x3⅛x3.58
Plates	Pl. 12x¼
Square Bar	1 ▣
Rod	¾ Φ
Rectangular Bar	Bar 2x3/16

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Warranty. Alcoa warrants that the goods to be supplied hereunder will conform to the description on the face hereof; that it will convey good title thereto; that such goods will be delivered free from any lawful security interest or other lien or encumbrance unknown to the Customer, and that such goods will be merchantable and free from defects in material and workmanship. There is no warranty that the goods shall be fit for any particular purpose, nor is there any other warranty, express or implied, except such as is expressly set forth herein. Alcoa shall not be liable for any incidental or consequential damages for any breach of warranty, Alcoa's liability and Customer's exclusive remedy being expressly limited to the repair or replacement, without cost to the Customer, of defective goods, or the repayment of the purchase price upon return of the goods. Goods may be returned at the cost of Alcoa only after inspection by Alcoa and upon receipt by Customer of definite shipping instructions from Alcoa.

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Alclad Aluminum
- Pipe
- Plate
- Rod
- Sheet
- Tube
- Wire

Aluminas (See Chemicals)

Aluminum Fluoride

Angles

Automotive Brake Pistons

Bar
- Hexagonal
- Rectangular
- Special Shapes
- Screw Machine Stock

Beer Barrels

Bolts

Brazing Wire and Flux

Bulb Angles

Bus (See Electrical Conductors)

Cable (See Electrical Conductors)

Casting Alloy Ingot

Castings
- Die
- Permanent Mold
- Plaster Mold
- Sand Mold
- Semipermanent Mold

Castings (*Continued*)

Channels

Chemicals
- Aluminas
  - Activated
  - Calcined
  - Catalytic
  - Hydrated
  - Low Soda
  - Tabular
- Aluminum Fluoride
- Atomized and Flaked Aluminum Powder
- Cryolite—Fluxing
- Insecticide
- Fluoboric Acid
- Gallium
- Sodium Acid Fluoride
- Sodium Fluoride
- Sodium Fluoborate

Catalysts (See Chemicals)

Circles, Sheet and Plate

Closures, Bottle Sealing Machines

Coiled Sheet

Coiled Tube

Cold-heading Products

Collapsible Tubes for packaging tooth paste, drugs, calking compounds, greases, etc.

Collapsible Tube Slugs

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- Conduit, Rigid
- Construction Pipe
- Copings
- Corrugated Sheet
- Cryolite (See Chemicals)
- Die Castings
- Draw Press Products
- Drums, Shipping
- Electrical Conductors
  - Cable, All-aluminum or ACSR (Aluminum Conductor Steel Reinforced) Bare or Covered Cable and Wire Accessories
  - Wire, Bare or Covered
  - Bus Conductors
    - Angles
    - Channels
  - Rectangular
    - Solid Rounds
    - Special Shapes
    - Tubular
  - Bus Accessories
  - Fuse Wire
- Electrical Metallic Tube
- Engine Pistons
- Extruded Shapes
- Fasteners
  - Bolts
  - Nails
  - Nuts
  - Rivets
  - Screws
  - Screw Machine Products
  - Washers
- Finishes
  - Alrok
  - Alumilite
  - Electroplating
  - Other finishes are available
- Fluoboric Acid
- Fluorides (See Chemicals)
- Foil
  - Barrier
  - Electrical Condensers
  - Insulating & Moistureproof
  - Lithoplates
  - Milk Bottle Hoods
  - Packaging
  - Pie Plates & Food Containers
- Forgings, Hammer, Press, Upset, Hand (Open Die)
- Forging Stock
- Fuse Wire
- Gallium
- Grained Ingot
- Gravel Stops
- H-Beams
- Hammer Forgings
- Hand (Open Die) Forgings
- Handrail Pipe and Fittings
- Heat Exchanger Tubes
- Highway Railing (See Pipe and Tube)
- I-Beams
- Impact Products and Slugs
- Ingot
  - Casting Alloy
  - For Wrought Products
  - Metallurgical Granulated
- Insecticide, Cryolite
- Irrigation Pipe
- Lighting Sheet
- Lithograph Sheet and Foil
- Manhole Steps, Forged
- Meathooks, Forged
- Milk Bottle Hoods, Foil
  - Dairy Machines
- Moldings (See Extruded Shapes)

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- Nuts
- Numerals
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- Patterned Sheet
- Permanent Mold Castings
- Piano Plates
- Pig
- Pigments
  - Powder and Paste for printing ink and paper coating
- Pipe (See Tube)
  - Construction
  - Handrail and Fittings
  - Highway Railing
  - Irrigation
  - Standard and Fittings
  - Steam-traced (Unitrace)
- Pistons—Engine, Automotive Brake
- Plate (See Sheet)
  - Alclad
  - Circles
  - Odd-shaped Blanks with sheared or sawed edges
  - Rectangular
  - Tapered
  - Tread
- Plaster Mold Castings
- Powder, Aluminum (See Pigments) Atomized and Flaked for pyrotechnics, explosives and chemical uses
- Press Forgings
- Process Equipment (Made to Specification)
- Rectangular Tube
- Rectangular Wire and Bar
- Reflector Sheet
- Ring Rolled Products
- Rivets—Solid and Semitubular
- Rivet Wire, Rod
- Rod
  - Redraw
  - Rivet
  - Screw Machine Stock
- Roofing Sheet
- Sand Castings
- Screening Wire
- Screws
  - Machine
  - Sheet Metal
  - Special Types
  - Wood
- Screw Machine Products (Made to Specification)
- Screw Machine Stock (See Rod, Bar)
- Seals (Bottle Closures) and Sealing Machines
- Sheet (See Plate)
  - Alclad
  - Circles
  - Coiled
  - Flat
  - Odd-shaped Blanks with sheared or sawed edges
- Specialty Sheet
  - Alumilite
  - Brazing
  - Corrugated
  - Lithographed
  - Patterned
  - Recording Circles
  - Reflector
  - Roofing
  - Siding
  - Tapered
- Shipping Containers
  - Beer Barrels
  - Drums

Continued on next page

ALCOA PRODUCTS—*Concluded*

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Slugs, Collapsible Tube and Impact

Sodium Fluoborate

Solder and Flux

Spandrels

Special Cold-head Products

Square Tube

Structural Assemblies (Made to Specification)

Structural Shapes (Rolled and Extruded)

Tanks, Welded

Tees

Thread Lubricant and Compound

Thresholds

Tool and Jig Plates

Tooth Paste Tubes

Tread Plate

Tube (See also Pipe)
- Alclad
- Coiled
- Electrical Metallic
- Heat Exchanger
- Highway Railing
- Round
- Square
- Special Shapes

Tubes, Collapsible

Upset Forgings

Welding Materials
- Flux
- Rod
- Wire

Washers

Wheels for trucks, trailers and buses
- Disc
- Spoke

Wide-flange Sections

Window Sills

Wing Channels

Wire
- Alclad
- Brazing
- Flattened
- Hexagonal
- Rectangular
- Rivet
- Round
- Special Shapes
- Welding

Wire, Electrical (See Electrical Conductors)

Zees

COMMERCIAL FORMS OF MAGNESIUM PRODUCTS sold by Alcoa include Castings, Forgings, Extrusions, Tube and Pipe, Rod and Bar, and Structural Shapes. Also available are Pipe Line and Water Tank Anodes.

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SUPPLEMENT

A Reprint of ASCE Proceedings Papers—Nos. 3341 and 3342

Paper No. 3341

SUGGESTED SPECIFICATIONS FOR STRUCTURES OF ALUMINUM ALLOYS 6061-T6 and 6062-T6

Report of the Task Committee on Lightweight Alloys, Committee on Metals, Structural Division

Paper No. 3342

SUGGESTED SPECIFICATIONS FOR STRUCTURES OF ALUMINUM ALLOY 6053-T5 and 6063-T6

Report of the Task Committee on Lightweight Alloys, Committee on Metals, Structural Division

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Journal of the
STRUCTURAL DIVISION
Proceedings of the American Society of Civil Engineers

SUGGESTED SPECIFICATIONS FOR STRUCTURES OF ALUMINUM ALLOYS 6061-T6 AND 6062-T6

Report of the Task Committee on Lightweight Alloys
Committee on Metals, Structural Division

COMMITTEE REPORT

The Task Committee on Lightweight Alloys (formerly the Committee on Design in Lightweight Structural Alloys) has prepared two suggested specifications for the design of structures of aluminum alloys. The first of these is for 6061-T6 and 6062-T6 alloys (Proc. Paper 3341) and supersedes the previous specifications (1), (a).[1] The second specification is for alloy 6063-T5 and 6063-T6 (Proc. Paper 3342). The task committee hopes that those who have constructive comments on, or criticism of, the suggested specifications will submit them to the Society.

POLICY OF THE STRUCTURAL DIVISION, ASCE, RELATIVE TO STRUCTURAL SPECIFICATIONS

(Adopted by the Executive Committee, Structural Division, on May 26, 1962)

No specification shall be issued in the name of, nor be endorsed by, the Structural Division of ASCE.

Specifications may be prepared by Task Committees of the Structural Division, ASCE, working alone or jointly with other groups. Such specifications may be submitted as committee reports, through the Executive Committee of the Division, for publication in the Structural Division Journal.

Note.—Discussion open until May 1, 1963. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. ST6, December, 1962.

[1] Numerals in parentheses refer to corresponding items in Appendix I.

The Structural Division Executive Committee requests that any committee report that takes the form of a specification, and is written in the usual terse specification style, be accompanied by a commentary or discussion supporting and explaining the specification. The Executive Committee will submit such a report for publication, after the necessary review and approval.

It is the desire and intent of the Structural Division Executive Committee that the best interests of the members of ASCE and the engineering profession be served. Where this is best accomplished by publication and open discussion of design specifications in the Division Journal, this will be done. The Committee feels that no useful purpose will be served by ASCE endorsement of specifications; however, constructive criticism and discussion will add materially to the understanding and improvement of specifications.

FOREWORD

These specifications supersede two previous sets of specifications for structures of aluminum alloy 6061-T6, prepared by this committee (1),(2).

SYNOPSIS

These specifications cover allowable stresses, design rules, and fabrication procedures for structures built of the aluminum alloys known commercially as 6061-T6 and 6062-T6. Alloy 6061-T6 is available in the form of sheet, plate, shapes, tubes, rods, bars, rivets and forgings. Alloy 6062-T6 is available in the form of shapes and tubes. The two alloys have the same mechanical properties and may be used interchangeably. Two sets of allowable stresses are provided; one for bridges and other structures to which allowable stresses for bridges are normally applied; the other for buildings and other structures to which allowable stresses for buildings are normally applied. The basic allowable stresses are 17 ksi for bridge structures and 19 ksi for building structures, based on a minimum yield strength of 35 ksi and a minimum tensile strength of 38 ksi.

PART I.—GENERAL

Introduction.—These specifications cover the allowable stresses, the design rules, and the fabrication procedures for two aluminum alloys commonly used for structural purposes where a high degree of resistance to corrosion is de-

sired. In the preparation of these specifications the Committee has made use of the available theoretical and experimental work relating to this subject and particularly to the Committee's previously published specifications.

These specifications are confined to allowable stresses, design rules, and fabrication. No attempt has been made to cover the loading, erection, inspection, or nontechnical provisions included in many specifications, because such provisions are fairly well established in current good structural practice. It is intended, of course, that structures built under these specifications will be designed, constructed, and erected by following current good practice for metal structures.

It is believed that the designer can make more effective use of a set of specifications if he knows the basis for its various provisions. For this reason the section, "Explanation of Specifications," has been added. That section contains background information and references concerning those paragraphs of the specifications for which some explanation seems required.

When the abbreviation "ksi" is used in these specifications it denotes "kips per square inch" or "thousands of pounds per square inch."

Material.—The principal materials considered in these specifications are aluminum alloys having the following nominal chemical compositions:

Composition	Percentage by weight 6061-T6	6062-T6
Copper	0.25	0.25
Silicon	0.6	0.6
Magnesium	1.0	1.0
Chromium	0.25	0.06
Aluminum	97.9	98.09
Total	100.0	100.0

These materials are covered by the following American Society for Testing and Materials (ASTM) specifications:

Product	ASTM Specification No.
Sheet and Plate	B209-62 (6061-T6)
Drawn Seamless Tubes	B210-62 (6061-T6 and 6062-T6)
Bars, Rods and Wire	B211-62 (6061-T6)
Extruded Bars, Rods and Shapes	B221-62 (6061-T6 and 6062-T6)
Drawn Seamless Tubes for Condensers and Heat Exchangers	B234-62 (6061-T6 and 6062-T6)
Extruded Tubes	B235-62 (6061-T6 and 6062-T6)
Pipe	B241-62 (6061-T6 and 6062-T6)
Forgings	B247-62 (6061-T6)
Standard Structural Shapes	B308-62 (6061-T6 and 6062-T6)

For products that are available in both alloys, the two alloys may be used interchangeably.

The specified minimum tensile strength of these materials is 42 ksi for sheet and plate, drawn tubes, and bars, rods and wire; and 38 ksi for all other products. The specified minimum yield strength for all products is 35 ksi. The minimum mechanical properties that have been used as a basis for the selection of allowable stresses in these specifications are listed in Table 1.

TABLE 1.—BASIC STRENGTH DATA[a]

	Unaffected Parent Material	Material Affected by Heat of Welding	
		All material welded with 5356 or 5556 filler alloy and material 3/8-in. or less in thickness welded with 4043 filler alloy	Material more than 3/8-in. thick welded with 4043 filler alloy
Tensile strength	38	24[b]	24[b]
Tensile yield strength	35	20[c]	15[c]
Compressive yield strength	35	20[c]	15[c]
Shear strength	24	15	15
Shear yield strength	20	12	9
Bearing strength	80	50	50
Bearing yield strength	56	30	22

[a] Minimum strength values for Alloys 6061-T6 and 6062-T6, ksi.
[b] ASME weld qualification test value for tensile strength across a butt weld.
[c] These are expected minimum values of the yield strength across a butt weld, corresponding to 0.2% offset on a 10-in. gage length.

Materials for rivets, bolts, nuts, washers, and welding rods and electrodes are covered by the ASTM specifications listed in Table 2. Following are typical values of other physical properties of these alloys:

Modulus of elasticity, ksi	10,000
Modulus of elasticity in shear, ksi	3,800
Poisson's ratio	1/3
Coefficient of expansion, per degree Fahrenheit	0.000012
Weight, in pounds per cubic inch	0.098

Alloys 6061-T6 and 6062-T6 are the ones principally considered in the preparation of these specifications and the ones to which the allowable stresses for parts other than bolts apply. However, these specifications may be applied to structures built of other suitable aluminum alloys, provided such alloys meet the specified strengths and elongations listed in the ASTM specifications mentioned in the first paragraph of this section. Whether or not such other alloys need paint protection will depend on whether they are as resistant to corrosion as 6061-T6 and 6062-T6. The sections of this specification dealing

TABLE 2.—PERTINENT ASTM SPECIFICATIONS

Product	Alloy	ASTM Specification for Material from Which Product is Made
Rivets	6061-T6 or 6061-T4[a]	B316-62 - Rivet and Cold Heading Wire and Rods[b]
Bolts	2024-T4	B316-62 - Rivet and Cold Heading Wire and Rods[b]
Nuts	6061-T6 or 6262-T9	B211-62 - Bars, Rods and Wire, or B316-62 - Rivet and Cold Heading Wire and Rods[b]
Washers	Alclad 2024-T3 or -T4	B209-62 - Sheet and Plate
Welding Rods and Electrodes	ER4043, ER5356 or ER5556	B285-62T - Welding Rods and Bare Electrodes

[a] ASTM B316-61 includes mechanical property specifications for 6061-T6 but not 6061-T4. The heat treatment for the latter is the same as the former except that the artificial aging is omitted.

[b] ASTM B316-62 covers rods up to 0.615 in. in diameter. Rods with diameters from 0.615 to 1.000 in. are supplied with the same mechanical property limits and tolerances on diameter (+0.003 in., -0.001 in.) that apply to 0.615-in. rod in ASTM B316-62.

TABLE 3.—ALLOYS TO BE USED FOR RIVETS

Designation before driving	Driving procedure	Designation after driving	Typical shear strength[a]
6061-T6	Cold, as received	6061-T6	30
6061-T4	Hot, 990°F to 1,050°F	6061-T43	24

[a] Typical ultimate shear strength of the driven rivet, ksi.

with welding should not be applied to other alloys unless it has been clearly demonstrated that such alloys are suitable for welding.

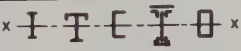
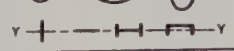
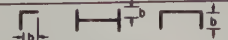
Rivets used in fabricating structures designed in accordance with these specifications shall be of aluminum alloy and may be either cold driven or hot driven. The alloy used is indicated in Table 3.

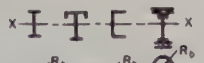
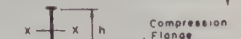
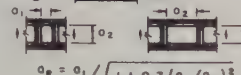
Aluminum bolts used in structures designed in accordance with these specifications shall be of alloy 2024-T4. Such bolts have expected minimum tensile and shear strengths of 62 ksi and 37 ksi, respectively.

PART II.—SPECIFICATIONS FOR RIVETED AND BOLTED STRUCTURES

Section A: Summary of Allowable Stresses.—The allowable stresses to be used in proportioning the parts of a structure shall be determined from Tables

TABLE 4a.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES IN WELDED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6061-T6 AND 6062-T6 BRIDGE STRUCTURES NONWELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1a	Any tension member	17				
TENSION in extreme fibers of beams, net section		A-2a	Structural shapes, rectangular tubes, built-up members bent about X-axis 	17				
		A-3a	Round or oval tubes	21				
		A-4a	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis 	23				
BEARING		A-5a	On rivets and bolts	30[a]				
		A-6a	On milled surfaces and pins	20				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs. A-8a to A-10a)	A-7a	Columns	17	$\frac{l}{r} = 9.2$	$18.1 - 0.120\frac{l}{r}$	$\frac{l}{r} = 67$	$\frac{45,000}{(l/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7a)	A-8a	Outstanding flanges and legs 	17	$\frac{b}{t} = 5.2$	$21.0 - 0.77\frac{b}{t}$	$\frac{b}{t} = 12$	$\frac{1,720}{(b/t)^2}$
		A-9a	Flat plates with both edges supported	17	$\frac{b}{t} = 17$	$21.0 - 0.24\frac{b}{t}$	$\frac{b}{t} = 38$	$\frac{17,000}{(b/t)^2}$
		A-10a	Curved plates supported on both edges and walls of round or oval tubes	17	$\frac{R}{t} = 20$	$20.0 - 0.68\sqrt{\frac{R}{t}}$	$\frac{R}{t} = 125$	- - - -

COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15a to A-19a)	A-11a	Single-web structural shapes and built-up sections bent about X-axis		17	$\frac{L_b}{r_y} = 11$	$18.1 - 0.100 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 80$	$\frac{65,000}{(L_b/r_y)^2}$
		A-12a	Round or oval tubes		21	$\frac{R_b}{t} = 21$	$25.0 - 0.19 \frac{R_b}{t}$	$\frac{R_b}{t} = 60$	- - - -
		A-15a	Solid rectangular beams bent about X-axis		23	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 12$	$31.0 - 0.70 \frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 27$	$\frac{8,800}{(\frac{d}{t})^2(\frac{L_b}{d})}$
		A-14a	Rectangular tubes and box sections		17	$\frac{L_b S_c}{I_y} = 33$	$18.1 - 0.192\sqrt{\frac{L_b S_c}{I_y}}$	$\frac{L_b S_c}{I_y} = 1760$	$\frac{17,700}{L_b S_c / I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. A-11a to A-14a)	A-15a	Flat plates with one edge free and one edge supported		17	$\frac{b}{t} = 6.0$	$21.0 - 0.87 \frac{b}{t}$	$\frac{b}{t} = 14$	$\frac{2,240}{(b/t)^2}$
		A-16a	Flat plates with both edges supported		17	$\frac{b}{t} = 17$	$21.0 - 0.24 \frac{b}{t}$	$\frac{b}{t} = 38$	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11a to A-14a)	A-17a	Flat plates with compression edge free and tension edge supported, bent about X-axis		23	$\frac{b}{t} = 7.3$	$31.0 - 1.1 \frac{b}{t}$	$\frac{b}{t} = 19$	$\frac{3,700}{(b/t)^2}$
		A-18a	Flat plates with both edges supported, bent about X-axis		17	- - - -	17	$\frac{h}{t} = 110$	$\frac{205,000}{(h/t)^2}$
		A-19a	Flat plates with both edges supported, bent about X-axis with horizontal stiffener		17	- - - -	17	$\frac{h}{t} = 227$	$\frac{880,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-20a	Unstiffened flat webs		11	$\frac{h}{t} = 13$	$12.1 - 0.082 \frac{h}{t}$	$\frac{h}{t} = 66$	$\frac{29,000}{(h/t)^2}$
		A-21a	Stiffened flat webs		11	- - - -	11	$\frac{a_e}{t} = 65$	$\frac{47,000}{(a_e/t)^2}$

$$a_e = a_1 \Big/ \sqrt{1 + 0.7\,(a_1/a_2)^2}$$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or greater. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

4a to 7a and 4b to 7b. The allowable stresses in Tables 4a through 7a are intended for application to bridge structures and other structures to which specifications similar to the AASHO (3) and AREA (4) specifications for steel bridges are applied. These specifications for bridge structures are designated by the numbers A-1a to A-25a and I-1a to I-24a.

The allowable stresses in Tables 4b through 7b, which appear in Appendix II, are intended for application to building structures and other structures to which specifications similar to the AISC specifications for steel buildings are applied. These specifications for building structures are designated by the numbers A-1b to A-25b and I-1b to I-24b. In subsequent sections of these specifications, when reference is made to a specification number such as "A-1," this number is intended to apply to either "A-1a" or "A-1b."

In applications where it is conventional practice to increase allowable stresses for certain types of loads, such as wind loads, the allowable stresses

TABLE 5a.—ALLOWABLE STRESSES IN RIVETS AND BOLTS (BRIDGE STRUCTURES)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear Area	Tension on root area
A-22a	6061-T6 rivets, cold driven	10	--
A-23a	6061-T43 rivets, driven at temperatures of from 990°F to 1,050°F	8	--
A-24a	2024-T4 bolts	14[a]	23
A-25a	6061-T6 pins	10	--

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

in these specifications should be increased in the same proportion as are the allowable stresses in accepted specifications for steel structures.

The terms appearing in the formulas in Tables 4a, 4b, 6a and 6b are defined as follows:

a_1 = shorter span of rectangular shear panel, in inches;

a_2 = longer span of rectangular shear panel, in inches;

a_e = equivalent span of rectangular shear panel, in inches;

b = clear width of outstanding flange or of flat plate supported on both unloaded edges, in inches;

d = depth of beam, in inches;

d_1 = distance from toe of compression flange to neutral axis, in inches;

h = clear height of shear web, in inches;

I_y = moment of inertia of a beam (about axis parallel to web), in.^{4};

L = length of compression member between points of lateral support or twice the length of a cantilever column (except where analysis shows that a shorter length can be used), in inches;

L_b = length of beam between points at which the compression flange is supported against lateral movement or length of cantilever beam from free end to point at which the compression flange is supported against lateral movement, in inches;

R = outside radius of round tube or maximum outside radius for an oval tube, in inches;

R_b = outside radius of a round tube in bending or outside radius at the location of the critical compressive stress for an oval tube in bending, in inches. (The location of the critical compressive stress is at the extreme fiber for an oval tube bent about the major axis. For an oval tube bent about the minor axis, the location of the critical stress can be determined by calculating the allowable stress at several points using the formulas of Specification A-12, with R_b equal to the outside radius at each point. Bending moments corresponding to the allowable stresses at the various points are calculated, and the point resulting in the smallest bending moment is the location of the critical compressive stress.);

r = least radius of gyration of a column, in inches;

r_y = radius of gyration of a beam about axis parallel to web, in inches. (For beams that are unsymmetrical about the horizontal axis, r_y should be calculated as though both flanges were the same as the compression flange.);

S_c = section modulus of a beam (compression side), in cubic inches; and

t = thickness of flange, plate, web or tube, in inches. (For tapered flanges, t is the average thickness.)

Section B: Column Design.

B-1: Allowable Compressive Stress in Columns.—The allowable compressive stress on the gross section of axially loaded columns shall be determined from the formulas in Specification A-7.

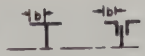
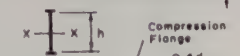
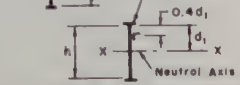
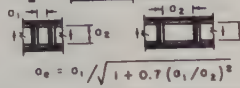
Columns having cross sections involving webs and outstanding legs of such proportions that local buckling may control the design shall be checked by Specifications A-8 to A-10 or by the method outlined in Part IV, Section M.

Open section members that are unsymmetrical about one or both principal axes may be subject to failure by combined torsion and flexure. For single or double angles and tee sections, Specification A-8 provides an adequate factor of safety against this type of failure. Other unsymmetrical, open shapes, such as channels, lipped angles or hat shapes should not be used as columns unless a special analysis is made of the resistance to buckling by combined torsion and flexure (17), (43).

B-2: Columns with Slenderness Ratio Exceeding 120.—Because long columns are relatively flexible, they may be appreciably weakened by the presence

TABLE 6a.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6061-T6 AND 6062-T6 BRIDGE STRUCTURES WELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		I-1a	Any tension member	10(b)				
TENSION in extreme fibers of beams, net section		I-2a	Structural shapes, rectangular tubes, built-up members bent about X-axis	10(b)				
		I-3a	Round or oval tubes	12(b)				
		I-4a	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	12(b)				
BEARING		I-5a	On rivets and bolts	16(b)(d)				
		I-6a	On milled surfaces and pins	11(b)				
				Allowable Stress for Slenderness Less Than S_1 ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, (a) gross section (Also see Specs. I-8a to I-10a)	I-7a	Columns (a)	10(b)	- - - -	10(b)	$\frac{l}{r} = 87$(c)	$\frac{45,000}{(l/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7a)	I-8a	Outstanding flanges and legs	10(b)	$\frac{b}{t} = 4.7$(c)	$\frac{21.6}{\sqrt{b/t}}$	$\frac{b}{t} = 19$	$\frac{1,720}{(b/t)^2}$
		I-9a	Flat plates with both edges supported	10(b)	- - - -	10(b)	$\frac{b}{t} = 41$(c)	$\frac{17,000}{(b/t)^2}$
		I-10a	Curved plates supported on both edges and walls of round or oval tubes	10(b)	$\frac{R}{t} = 13$(c)	$\frac{18.9}{(R/t)^{1/4}}$	$\frac{R}{t} = 200$	- - - -
COMPRESSION in Members Subjected	COMPRESSION (a) in extreme fibers of beams, gross section (Also see Specs. I-15a to I-19a)	I-11a	Single-web structural shapes and built-up sections bent about X-axis (a)	10(b)	- - - -	10(b)	$\frac{L_b}{r_y} = 81$(c)	$\frac{65,000}{(L_b/r_y)^2}$
		I-12a	Round or oval tubes	12(b)	$\frac{R_b}{t} = 11$(c)	$\frac{21.9}{(R_b/t)^{1/4}}$	$\frac{R_b}{t} = 135$	- - - -
		I-13a	Solid rectangular beams bent about X-axis	12(b)	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 9.8$(c)	$\frac{37.5}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 38$	$\frac{8,800}{(\frac{d}{t})^2 \frac{L_b}{d}}$
		I-14a	Rectangular tubes and box sections (a)	10(b)	- - - -	10(b)	$\frac{L_b S_c}{I_y} = 1770$(c)	$\frac{17,700}{L_b S_c / I_y}$

to Bending, Gross Section	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11a to I-14a)	I-15a	Flat plates with one edge free and one edge supported		$10^{(b)}$	$\frac{b}{t} = 5.1^{(c)}$	$\frac{22.5}{\sqrt{b/t}}$	$\frac{b}{t} = 21$	$\frac{2,240}{(b/t)^2}$
		I-16a	Flat plates with both edges supported		$10^{(b)}$	- - - -	$10^{(b)}$	$\frac{b}{t} = 41$	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11a to I-14a)	I-17a	Flat plates with compression edge free and tension edge supported, bent about X-axis		$12^{(b)}$	$\frac{b}{t} = 8.3^{(c)}$	$\frac{30.2}{\sqrt{b/t}}$	$\frac{b}{t} = 25$	$\frac{3,700}{(b/t)^2}$
		I-18a	Flat plates with both edges supported, bent about X-axis		$10^{(b)}$	- - - -	$10^{(b)}$	$\frac{h}{t} = 143^{(c)}$	$\frac{205,000}{(h/t)^2}$
		I-19a	Flat plates with both edges supported, bent about X-axis with horizontal stiffener		$10^{(b)}$	- - - -	$10^{(b)}$	$\frac{h}{t} = 300^{(c)}$	$\frac{880,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-20a	Unstiffened flat webs		$6^{(b)}$	- - - -	$6^{(b)}$	$\frac{h}{t} = 70^{(c)}$	$\frac{29,000}{(h/t)^2}$
		I-21a	Stiffened flat webs		$6^{(b)}$	- - - -	$6^{(b)}$	$\frac{a_e}{t} = 88^{(c)}$	$\frac{47,000}{(a_e/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification I-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy and to material 3/8-in. or less in thickness welded with 4043 filler alloy. For thicker material welded with 4043 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a superscript apply to material welded with either 4043, 5556 or 5356 filler alloy.

(c) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy and to material 3/8-in. or less in thickness welded with 4043 filler alloy. For thicker material welded with 4043 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in Note (b) above.

(d) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

of lateral loads that would have little effect on the column strength of stiffer members. For this reason, columns with slenderness ratios greater than 120 should not be used unless special care is taken to insure that the effects of any lateral loads to which the member may be subjected, such as wind, dead load, or the weight of workmen and equipment, are taken into account by using the provision for combined compression and bending in Specifications B-7.

B-3: Compression Splices.—Members designed for compression, if faced for bearing, shall be spliced on four sides sufficiently to hold the abutting parts true to place. The splice shall be as near a panel point as practicable and shall be designed to transmit at least one half of the stress through the splice material. Members not faced for bearing shall be fully spliced for the computed stress. In either case, adequate provision shall be made for transmitting shear.

TABLE 7a.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS (BRIDGE STRUCTURES)

Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-22a	5556	7.5	8[c]
I-23a	5356	6.5	8[c]
I-24a	4043	4.5	6

[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

B-4: Stay Plates.—On the open sides of compression members without webs, the flanges shall be connected by lacing bars, with stay plates as near each end as practicable, or by perforated cover plates. There shall be stay plates at intermediate points where the lacing is interrupted. The length of the end stay plates shall not be less than one and one-fourth times the distance between the nearest lines of connecting rivets, bolts or welds. The thickness of stay plates shall not be less than one fortieth of the distance between lines of connections.

B-5: Diagonal Lacing.—The slenderness ratio of the part of the flange between the lacing bar connections shall not be more than three-fourths of the slenderness ratio of the member.

B-6: Perforated Cover Plates.—Perforated cover plates may be used instead of tie plates and lacing, provided that: The ratio of length (in direction of stress) to width of hole shall not exceed 2; the clear distance between holes shall not be less than the distance between nearest lines of connecting rivets, bolts or welds; the periphery of the holes at all points shall have a minimum radius of 1 1/2 in.; the thickness of the cover plate shall not be less than one

fortieth of the distance between the nearest lines of connecting rivets, bolts or welds; and the stress on the net section of the column (omitting the area of the holes in the cover plate) shall not exceed the values given in Specification A-8 or I-8, where t is the thickness of the perforated cover plate and b is the distance from the edge of the hole to the nearest line of connecting rivets, bolts, or welds.

B-7: Combined Compression and Bending.—A member that carries bending moment in addition to uniform compression (as, for example, an eccentrically loaded column) shall be proportioned in accordance with the following formulas:

For members subjected to combined end load and bending, where the bending moment at the center of the span is equal to or greater than 0.9 of the maximum bending moment in the span.

$$\frac{f_a}{F_a} + \frac{f_b}{F_b\left(1 - \frac{f_a}{F_e}\right)} \leq 1 \quad \ldots\ldots\ldots\ldots \quad (1)$$

in which f_a is the average compressive stress on cross section of member produced by axial compressive load, ksi; f_b denotes the maximum bending stress (compression) caused by transverse loads or end moments in the absence of axial load, ksi; F_a refers to the allowable compressive stress for member considered as an axially loaded column, ksi; and F_b describes the allowable compressive stress for member considered as a beam, ksi.

For bridges and similar structures,

$$F_e = \frac{45{,}000}{\left(\frac{L}{r}\right)^2}$$

For buildings and similar structures,

$$F_e = \frac{51{,}000}{\left(\frac{L}{r}\right)^2}$$

in which L/r is the slenderness ratio for a member considered as a column tending to fail in the plane of the applied bending forces.

For members subjected to combined end load and bending where the bending moment at the center of the span is not more than one-half the maximum bending moment in the span.

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

For members subjected to combined end load and bending where the moment at the center of the span is between 0.5 and 0.9 of the maximum moment,

$$\frac{f_a}{F_a} + \frac{f_b}{F_b\left[1 - \left(\frac{2\,M_c}{M_m} - 1\right)\frac{f_a}{F_e}\right]} \leq 1 \quad \ldots\ldots\ldots \quad (3)$$

in which M_c describes the bending moment at center of span resulting from applied bending loads, in-kips; and M_m denotes maximum bending moment in span resulting from applied bending loads, in-kips.

B-8: Transverse Shear in Columns.—In designing lacing or shear webs for columns, the maximum shear on the column shall be computed from the formula:

$$V = 0.02\,(F_c)_{max}\,A + V_t \quad \ldots\ldots\ldots\ldots \quad (4)$$

in which V is the maximum shear on any transverse section of a column, kips; A denotes the gross area of column cross section, in square inches; $(F_c)_{max}$ is the maximum allowable compressive stress for short columns, ksi (for example, $(F_c)_{max} = 17$ for unwelded columns in bridge structures); and V_t refers to the shear caused by any transverse loads on the column, kips.

Section C: Beam and Girder Design.

C-1: Allowable Compressive Stress in Beams.—The allowable compressive stress in extreme fibers of beams shall be determined from the formulas in Specifications A-11 to A-14.

Beams whose compression flanges involve webs or outstanding legs of such proportions that local buckling may control the design shall be checked by Specifications A-15 to A-19 or by the method outlined in Part IV, Section M.

C-2: Single-Web Beams.—Because of the simplified form of the formulas for allowable stress in single-web beams and girders in Specification A-11, these formulas give very conservative values of allowable stress for certain conditions, namely for values of L_b/r_y exceeding approximately 50, for load distributions such that the bending moment near the center of the beam is appreciably less than the maximum bending moment in the beam or for beams with transverse loads applied to the bottom flange. If the designer wishes to compute more precise values of allowable stress for single-web beams and girders, he may make use of the formulas in Part IV, Section L.

C-3: Allowable Shear Stresses in Webs.—The allowable shear stress in flat webs shall not exceed the values given in Specifications A-20 for unstiffened webs or Specification A-21 for stiffened webs.

Section D: Design of Plates, Legs, and Webs in Compression.

D-1: Single-Angle, Double-Angle, Tee, or Cruciform Struts.—For struts consisting of a single angle, double angle, tee, or cruciform section, the compressive stress on the gross area shall not exceed the value given by Specification A-7 or by Specification A-8, whichever is smaller.

D-2: Flat Plate Elements of Columns.—For compression members other than those consisting of a single angle, double angle, tee, or cruciform section,

the allowable compressive stress shall not exceed the value given by Specification A-7 nor shall it exceed the values given by Specifications A-9 or A-10 unless the special analysis described in Part IV, Section M is utilized.

D-3: Flat Plate Elements of Beams.—Allowable compressive stresses in flat plate elements of beams shall not exceed the values given by Specification A-15 or A-16, unless the special analysis described in Part IV, Section M, is used.

D-4: Stiffeners for Outstanding Flanges.—Outstanding flanges stiffened by lips or bulbs at the free edge shall be considered as supported on both edges if the moment of inertia of the lip or bulb meets the following requirement:

$$I_L = \frac{b^3 t}{80} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5a)$$

in which b is the clear width of flange, in inches; t denotes the thickness of flange, in inches; and I_L refers to the moment of inertia of lip or bulb about face of flange from which lip projects, in.^{4}.

For rectangular lips having the same thickness as the flange, the preceding requirement may be expressed

$$b_L = \frac{1}{3} b \quad \ldots\ldots\ldots\ldots\ldots\ldots (5b)$$

in which b_L is the clear width of the lip, in inches. Allowable stresses for flanges with lips or bulbs meeting the foregoing requirements shall be determined from Specification A-9 or A-16. The area of stiffening lips or bulbs is included with the area of the rest of the section in calculating the stresses caused by the loads.

Section E: Plate Girder Design.

E-1: Proportioning Plate Girders.—Plate girders shall be proportioned by the moment of inertia method, with the gross section used to determine the moment of inertia.

The stress on the net area of the tension flange shall be found by multiplying the stress on the gross section by the ratio of the gross area of the tension flange to the net area. In determining this ratio the tension flange shall be considered to consist of the flange angles and cover plates plus one-sixth of the web.

E-2: Allowable Flange Stress.—The allowable compressive stress in the extreme fiber of plate girders shall be determined as outlined in Sections C and D.

E-3: Flange Cover Plates.—Cover plates shall extend far enough to allow at least two extra rivets at each end of the plate beyond the theoretical end, and the spacing of the rivets in the remainder of the plate shall be such as to develop the required strength of the plate at any section.

E-4: Flange Rivets.—The flanges of plate girders shall be connected to the web with enough rivets or bolts to transmit the longitudinal shear at any point together with any load that is applied directly on the flange.

E-5: Flange Splices.—It is preferable that flange angles be spliced with angles.

E-6: Allowable Web Stresses.—The allowable shear stress in the webs of plate girders shall not exceed the values given by Specification A-20 to A-21. The longitudinal compressive stress in webs of plate girders at the toe of the compression flange shall not exceed the values given by Specification A-18 or A-19.

E-7: Web Splices.—It is preferable that splices in the webs of plate girders be made with splice plates on both sides of the web.

E-8: Size of Vertical Stiffeners to Resist Shear Buckling.—Stiffeners applied to plate girder webs to resist shear buckling shall have a moment of inertia not less than the values given by the following formulas:

For bridges and similar structures,

$$\frac{s}{h} \leq 0.4, \quad I_s = \frac{V h^2}{16{,}600} \left(\frac{s}{h}\right) \quad \ldots\ldots\ldots (6a)$$

$$\frac{s}{h} > 0.4, \quad I_s = \frac{V h^2}{104{,}000} \left(\frac{h}{s}\right) \quad \ldots\ldots\ldots (7a)$$

For buildings and similar structures,

$$\frac{s}{h} \leq 0.4, \quad I_s = \frac{V h^2}{18{,}700} \left(\frac{s}{h}\right) \quad \ldots\ldots\ldots (6b)$$

$$\frac{s}{h} > 0.4, \quad I_s = \frac{V h^2}{117{,}000} \left(\frac{h}{s}\right) \quad \ldots\ldots\ldots (7b)$$

in which s denotes the stiffener spacing, in inches; h is the clear height of web, in inches; V refers to the shear force on the web at the stiffener location, kips; and I_s is the moment of inertia of stiffener, in.^{4}.

Where a stiffener is composed of a pair of members, one on each side of the web, the distance s shall be the clear distance between the stiffeners. Where a stiffener is composed of a member on one side of the web only, the distance s shall be the distance between rivet lines. In determining the allowable shear stresses in panels containing a horizontal stiffener located as indicated in Specification A-19, the vertical height of the panel, a_1 or a_2, in Specification A-21 may be taken as 90% of the clear height between flanges.

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the centerline of the web. For a stiffener composed of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener. In determining the required moment of inertia of stiffeners, the term h shall always be taken as the full clear height between flanges, regardless of whether or not a horizontal stiffener is present.

E-9: Vertical Stiffeners at Points of Bearing.—Stiffeners shall be placed in pairs at end bearings of plate girders and at points of bearing of concentrated loads. They shall be connected to the web by enough rivets to transmit the load. Such stiffeners shall have a close bearing against the loaded flanges.

Only that part of the stiffener cross section which lies outside the fillet of the flange angle shall be considered effective in bearing. Bearing stiffeners shall not be crimped.

The moment of inertia of the stiffener shall not be less than that given by the following formulas:

For bridges and similar structures,

$$I = I_s + \frac{P\,h^2}{45{,}000} \quad \ldots\ldots\ldots\ldots\ldots (8a)$$

For buildings and similar structures,

$$I = I_s + \frac{P\,h^2}{51{,}000} \quad \ldots\ldots\ldots\ldots\ldots (8b)$$

in which I is the required moment of inertia of bearing stiffener, in.^{4}; I_s denotes the moment of inertia required to resist shear buckling (Specification E-8), in.^{4}; P refers to the local load concentration on the stiffener, kips; and h describes the clear height of the web between flanges, in inches.

E-10: Horizontal Stiffeners.—If a horizontal stiffener is used on a plate girder web, it shall be located so that the distance from the toe of the compression flange to the centroid of the stiffener is 0.4 of the distance from the toe of the compression flange to the neutral axis of the girder. The horizontal stiffener shall have a moment of inertia not less than that given by the formula:

$$I_h = 2\,\alpha\,f\,t\,h^3 \left[\left(1 + 6\,\frac{A_h}{h\,t}\right)\left(\frac{s}{h}\right)^2 + 0.4\right] 10^{-6} \quad \ldots\ldots (9)$$

in which I_h denotes the moment of inertia of the horizontal stiffener, in.^{4}; α refers to a factor equal to unity for a stiffener consisting of equal members on both sides of the web and equal to 3.5 for a stiffener consisting of a member on one side only; h is the clear height of web between flanges, in inches; t describes the thickness of web, in inches; f is the compressive stress at the toe of the flange angles, ksi; s is the distance between vertical stiffeners, in inches; and A_h refers to the gross area of cross section of the horizontal stiffener, in square inches.

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the centerline of the web. In the case of a stiffener consisting of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener.

Eq. 9 must be solved by trial, since both the moment of inertia, I_h, and the area, A_h, of the stiffener are unknown. It is generally convenient to assume as a first approximation that the ratio $A_h/(ht)$ has the value 0.1.

Section F: Riveted and Bolted Connections.

F-1: Allowable Loads.—The allowable loads on rivets and bolts shall be calculated using the allowable shear stresses in Specifications A-22 to A-25 and the allowable bearing stresses in Specification A-5. In the latter specifi-

cation, the allowable bearing stress depends on the ratio of edge distance to rivet or bolt diameter, where the edge distance is the distance from the center of the rivet or bolt to the edge of a plate or shape toward which the pressure of the rivet or bolt is directed.

F-2: Effective Diameter.—The effective diameter of rivets shall be taken as the hole diameter, but shall not exceed the nominal diameter of the rivet by more than 4% for cold driven rivets or 7% for hot driven rivets. The effective diameter of pins and bolts shall be the nominal diameter of the pin or bolt.

F-3: Shear Area.—The effective area of a rivet or bolt in any shear plane shall be based on the effective diameter, except that for bolts with threads included in the shear plane, the effective shear area shall be based on the root diameter. Shear areas of rivets are listed with recommended hole sizes in Table 8.

F-4: Bearing Area.—The effective bearing area of pins, bolts, and rivets shall be the effective diameter multiplied by the length in bearing, except that for countersunk rivets, half of the depth of the countersink shall be deducted from the length.

F-5: Arrangement and Strength of Connections.—Connections shall be arranged to minimize the eccentricity of loading on the member. Members and connections shall be proportioned to take into account any eccentricity of loading by the connections.

F-6: Net Section.—The net section of a riveted or bolted tension member is the sum of the net sections of its component parts. The net section of a part is the product of the thickness of the part multiplied by its least net width. The net width for a chain of holes extending across the part in any straight or broken line shall be obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding $s^2/4g$ for each gage space in the chain. In the correction quantity $s^2/4g$, s denotes spacing parallel to direction of load (pitch) of any two successive holes in the chain, in inches, and g refers to spacing perpendicular to direction of load (gage) of the same holes, in inches.

The net section of the part is obtained from that chain which gives the least net width. The hole diameter to be deducted shall be the actual hole diameter for drilled or reamed holes and the hole diameter plus 1/16 in. for punched holes.

For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of the angle, less the thickness.

For splice members, the thickness shall be only that part of the thickness of the member that has been developed by rivets or bolts beyond the section considered.

F-7: Effective Sections of Angles.—If an angle in tension is connected on one side of a gusset plate, the effective section shall be the net section of the connected leg plus one half of the section of the outstanding leg unless the outstanding leg is connected by a lug angle. In the latter case, the effective section shall be the entire net section of the angle. The lug angle shall be designed to develop at least one-half the total load in the member and shall be connected to the main member by at least two fasteners.

F-8: Grip of Rivets and Bolts.—If the grip of rivets or bolts carrying calculated stress exceeds four and one-half times the diameter, the allowable

TABLE 8.—RECOMMENDED HOLE SIZES FOR ALUMINUM ALLOY RIVETS

Rivet Diameter, in inches	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
COLD DRIVEN RIVETS								
Hole Diameter, in inches	0.386	0.453	0.516	0.578	0.641	0.766	0.891	1.016
Drill Size	W	29/64	33/64	37/64	41/64	49/64	57/64	1-1/64
Single Shear Area, in square inches	0.1170	0.1612	0.2091	0.2624	0.3227	0.4608	0.6235	0.8107
HOT DRIVEN RIVETS								
Hole Diameter, in inches	0.397	0.469	0.531	0.594	0.656	0.781	0.922	1.063
Drill Size	X	15/32	17/32	19/32	21/32	25/32	59/64	1-1/16
Single Shear Area, in square inches	0.1238	0.1728	0.2215	0.2771	0.3380	0.4791	0.6677	0.8875

load per rivet or bolt shall be reduced. The reduced allowable load shall be the normal allowable load divided by (1/2 + G/9D) in which G is the grip, and D the nominal diameter of the rivet or bolt. If the grip of a rivet exceeds six times the diameter, special care shall be taken in driving to insure that the holes will be filled completely.

F-9: Spacing of Rivets and Bolts in Built-up Compression Members.—The pitch in the direction of stress shall be such that the allowable stress on the individual outside plates and shapes, treated as columns having a length equal to the rivet or bolt pitch in accordance with Specification A-7, exceeds the calculated stress. The gage at right angles to the direction of stresses shall be such that the allowable stress in the outside plates, treated as plates having a width b equal to the rivet or bolt gage, in accordance with Specification A-9, exceeds the calculated stress.

F-10: Stitch Rivets and Bolts.—Where two or more web plates are in contact, there shall be stitch rivets or bolts to make them act in unison. In compression members, the pitch and gage of such rivets or bolts shall be determined as outlined in Specification F-9. In tension members, the maximum pitch or gage of such rivets shall not exceed a distance, in inches, equal to (3 + 20t) in which t is the thickness of the outside plates, in inches. In tension members composed of two angles in contact, the pitch of the stitch rivets or bolts shall not exceed 10 in. in the case of bridges and similar structures or 20 in. for buildings and similar structures, nor shall such a member have less than two stitch rivets or bolts.

F-11: Minimum Spacing of Rivets and Bolts.—The distance between centers of rivets shall not be less than three times the diameter of the rivets and the distance between centers of bolts shall not be less than 2 1/2 times the diameter of the bolts.

F-12: Edge Distance of Rivets or Bolts.—The distance from the center of a rivet or bolt to a sheared, sawed, rolled, or planed edge shall be not less than one and one-half times the diameter, except in flanges of beams and channels, where the minimum distance may be one and one-fourth times the diameter. For rivets or bolts under computed stress, the distance from the center of the rivet or bolt to the edge of the plate or shape toward which the pressure of the rivet or bolt is directed should normally be at least twice the nominal diameter of the rivet or bolt. In cases in which a shorter edge distance must be used, the allowable bearing stress shall be reduced in accordance with Table 4[a].

The distance from the edge of a plate to the nearest rivet or bolt line shall not exceed six times the thickness of the plate.

F-13: Extra Rivets or Bolts.—If rivets or bolts carrying calculated stress pass through fillers more than 1/4 in. thick, the fillers shall be extended beyond the connected member and the extension secured by enough additional rivets or bolts to distribute the total stress in the member uniformly over the combined section of the member and filler.

Section G: Miscellaneous Design Rules.

G-1: Reversal of Load.—Members in structures subject to reversal of load under one passage of live load shall be proportioned as follows: Determine the tensile load and the compressive load and increase each by 50% of the smaller; then proportion the member and its connections so that the allowable stresses given in Sections A through F will not be exceeded by either increased load.

G-2: Slenderness Ratio of Tension Members.—Tension members with values of slenderness ratio L/r greater than 150 shall not be used unless care is taken to insure that such members are designed to resist any lateral loads such as wind, dead load, or the weight of workmen and equipment. Stresses caused by the combined bending and tensile loadings shall not exceed allowable limits.

G-3: Stay Plates for Tension Members.—Segments of tension members not directly connected to each other shall be stayed together. The length of the stay plate shall be not less than three-fourths of the distance between the nearest lines of connecting rivets, bolts, or welds. Stay plates that are fastened by rivets or bolts shall be connected to each segment of the tension member by at least two rivets or bolts. The distance between stay plates shall be such

TABLE 9.—ALLOWABLE TENSILE STRESSES FOR REPEATED LOADS IN RIVETED OR BOLTED CONSTRUCTION

Number of Repetitions of Load Application	Allowable Maximum Tensile Stress on Net Section, F_{max}, (a) ksi	
	$F_{min} \leq 0.5\ F_{max}$	$F_{min} > 0.5\ F_{max}$
100,000	F	F
500,000	$0.75F + 0.17\ F_{min}$	$0.53F + 0.66\ F_{min}$
1,000,000	$0.67F + 0.22\ F_{min}$	$0.50F + 0.68\ F_{min}$
2,000,000	$0.57F + 0.26\ F_{min}$	$0.42F + 0.72\ F_{min}$
10,000,000	$0.37F + 0.56\ F_{min}$	$0.33F + 0.73\ F_{min}$

F_{max} = allowable maximum tensile stress on net section for repeated loading, ksi;
F_{min} = minimum stress on net section during loading cycle, ksi (F_{min} is the smallest tensile stress in a tension-tension cycle or the largest compressive stress in a compression-tensile cycle. In the latter case, F_{min} is negative.); and
F = allowable stress for nonrepetitive loading, from Table 4a or 4b.
(a) In addition to the limitations given in this table, F_{max} must not exceed F nor the maximum tensile stress permitted by the reversal-of-load rule in Specification G-1.

that the slenderness ratio of the individual segments of the member between stay plates does not exceed the slenderness ratio of the member as a whole.

G-4: Fatigue.—Tests indicate that riveted members designed in accordance with the requirements of these specifications and constructed so as to be free from severe re-entrant corners and other unusual stress raisers will withstand at least 100,000 repetitions of maximum live load without fatigue failure regardless of the ratio of minimum to maximum load. Where a greater number of repetitions of some particular loading cycle is expected during the life of the structure, the calculated net section tensile stresses for the loading in question shall not exceed the values given in Table 9. Table 9 applies to both of the general types of structures considered in these specifications. When using Table 9, the reversal-of-load rule in Specification G-1 should be ignored. The final member and connections selected, however, shall be strong enough to satisfy the requirements of Specification G-1. In considering fatigue action

on structures, it is well to bear in mind the following points:

1. The most severe combination of loadings for which a structure is designed (dead load, maximum live load, maximum impact, maximum wind, and so forth) rarely occurs in actual service and is of little or no interest from the standpoint of fatigue.
2. The loading of most interest from the fatigue standpoint is the steady dead load with a superimposed and repeatedly applied live load having an intensity consistent with day-to-day normal operating conditions.
3. The number of cycles of load encountered in structures is usually small compared with those encountered in fatigue problems involving machine parts. For example, 100,000 cycles represent 10 cycles every day for 27 yr; 10,000,000 cycles represent 20 cycles every hour for 57 yr. Care must be taken not to overestimate grossly the number of cycles for any given load condition.
4. Careful attention to details in design and fabrication pays big dividends in fatigue life. When a fatigue failure occurs in a structure, it is usually at a point of stress concentration where the state of stress could have been improved with little or no added expense.

Section H: Fabrication.

H-1: Laying Out.

a. Hole centers may be center punched and cutoff lines may be punched or scribed. Center punching and scribing shall not be used where such marks would remain on fabricated material.

b. A temperature correction shall be applied where necessary in the layout of critical dimensions. The coefficient of expansion shall be taken as 0.000012 per degree Fahrenheit.

H-2: Cutting.

a. Material may be sheared, sawed, cut with a router, or arc cut. All edges which have been cut by the arc process shall be planed to a depth of 1/4 in. to remove edge cracks.

b. Cut edges shall be true and smooth, and free from excessive burrs or ragged breaks.

c. In bridge structures, sheared edges of plates carrying calculated stresses shall be planed to a depth of 1/4 in.

d. Re-entrant cuts shall be avoided wherever possible. If used, they shall be filleted by drilling prior to cutting.

e. Oxygen cutting of aluminum alloys is not permitted.

H-3: Heating.—Structural material shall not be heated, with the following exceptions:

a. Material may be heated to a temperature not exceeding 400°F for a period not exceeding 30 min in order to facilitate bending. Such heating shall be done only when proper temperature controls and supervision are provided to insure that the limitations on temperature and time are carefully observed.

b. Hot-driven rivets shall be heated as specified in Section H-5.

H-4: Punching, Drilling, and Reaming.—Rules for punching, drilling, and reaming are as follows:

a. In bridge structures, rivet or bolt holes in main members shall be subpunched or subdrilled and reamed to finished size after the parts are firmly

bolted together or shall be drilled to finished size after the parts are firmly bolted together. The amount by which the diameter of a subpunched hole is less than that of the finished hole shall be at least 1/4 the thickness of the piece and in no case less than 1/32 in. If the metal thickness is greater than the diameter of the hole, punching shall not be used.

b. Rivet or bolt holes in secondary material not carrying calculated stress may be punched or drilled to finish size before assembly.

c. The finished diameter of holes for cold-driven rivets shall be not more than 4% greater than the nominal diameter of the rivet. Recommended hole sizes are listed in Table 8.

d. The finished diameter of holes for hot-driven rivets shall be not more than 7% greater than the nominal diameter of the rivet. Recommended hole sizes are listed in Table 8.

e. The finished diameter of holes for bolts shall be not more than 1/16 in. larger than the nominal bolt diameter.

f. If any holes must be enlarged to admit the rivets or bolts, they shall be reamed. Poor matching of holes shall be cause for rejection. Holes shall not be drifted in such a manner as to distort the metal. All chips lodged between contacting surfaces shall be removed before assembly.

H-5: Riveting.

a. The driven head of aluminum alloy rivets preferably shall be of the flat or the cone-point type, with dimensions as follows:

1. Flat heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height not less than 0.4 times the nominal rivet diameter.

2. Cone-point heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height to the apex of the cone not less than 0.65 times the nominal rivet diameter. The included angle at the apex of the cone shall be approximately 127°.

b. Rivets shall be driven hot or cold as called for on the plans, provision for heating being as follows:

1. Hot-driven rivets shall be heated in a hot-air type furnace providing uniform temperatures throughout the rivet chamber and equipped with automatic temperature controls.

2. Hot-driven rivets shall be held at from 990°F to 1,050°F for not less than 15 min and for not more than 1 hr before driving.

3. Hot rivets shall be transferred from the furnace to the work and driven with a minimum loss of time.

c. Rivets shall fill the holes completely. Rivet heads shall be concentric with the rivet holes and shall be in proper contact with the surface of the metal.

d. Defective rivets shall be removed by drilling.

H-6: Painting.—Structures of the alloy covered by these specifications are not ordinarily painted except where (1) the aluminum alloy parts are in contact with, or are fastened to, steel members or other dissimilar materials, or (2) the structures are to be exposed to extremely corrosive conditions. Painting procedure is covered in the following paragraphs, and methods of cleaning and preparation are found in Specification H-7. (Treatment and paint-

ing of the structure in accordance with United States Military Specification MIL-T-704 is also acceptable.)

a. Where the aluminum alloy parts are in contact with, or are fastened to, steel members or other dissimilar materials, the aluminum shall be kept from direct contact with the steel or other dissimilar material by painting as follows:

1. Aluminum surfaces to be placed in contact with steel shall be given one coat of zinc chromate primer in accordance with United States Military Specification MIL-P-735 or the equivalent or one coat of a suitable nonhardening joint compound capable of excluding moisture from the joint during prolonged service. Additional protection can be obtained by applying the joint compound in addition to the zinc chromate primer. Zinc chromate paint shall be allowed to dry hard before assembly of the parts. The steel surfaces to be placed in contact with aluminum shall be painted with good quality priming paint, such as red lead conforming to Federal Specification TT-P-86 or zinc chromate primer in accordance with United States Military Specification MIL-P-735, followed by one coat of paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962-49, Type II, Class B) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or the equivalent. Stainless steel, or aluminized, hot-dip galvanized or electro-galvanized steel placed in contact with aluminum need not be painted.

2. Aluminum surfaces to be placed in contact with wood, concrete, or masonry construction, except where the aluminum is to be embedded in concrete, shall be given a heavy coat of an alkali-resistant bituminous paint before installation. The bituminous paint used shall meet the requirements of United States Military Specification MIL-P-6883. The paint shall be applied as it is received from the manufacturer without the addition of any thinner.

3. Aluminum surfaces to be embedded in concrete ordinarily need not be painted, unless corrosive components are added to the concrete or unless the concrete is subjected for extended periods to extremely corrosive conditions. In such cases, aluminum surfaces should be given one coat of suitable quality paint, such as zinc chromate primer conforming to United States Military Specification MIL-P-735 or equivalent, or should be wrapped with a suitable plastic tape applied in such a manner as to provide adequate protection at the overlap.

4. Water that comes in contact with aluminum after first running over a heavy metal such as copper may contain trace quantities of the dissimilar metal or its corrosion product, which will cause corrosion of the aluminum. Protection can be obtained by painting or plastic coating the dissimilar metal or by designing the structure so that the drainage from the dissimilar metal is diverted away from the aluminum.

5. Bolts and other fasteners used with aluminum shall be of aluminum, stainless steel, or aluminized, hot-dip galvanized or electro-galvanized steel.

b. Although structures of the alloy covered by these specifications are not ordinarily painted for surface protection, there may be applications where the structures are to be exposed to extremely corrosive conditions which make over-all painting advisable. In such instances, all contacting metal surfaces shall be painted before assembly with one coat of zinc chromate primer in accordance with United States Military Specification MIL-P-735 or the equiv-

alent. The primer shall be allowed to dry hard before assembly of the parts. All other surfaces shall be given one shop coat of zinc chromate primer made in accordance with United States Military Specification MIL-P-735 or the equivalent and then shall be given a second shop coat of paint consisting of 2 1/4 lb of nonleafing aluminum paste pigment (Alcoa No. 221, Reynolds 10 LN, or equivalent) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or the equivalent. The nonleafing paint shall be used to permit detection of an incomplete application of the subsequent paint coat. After erection, bare spots shall be touched-up with zinc chromate primer followed by a touch-up coat of nonleafing aluminum paint as specified previously. The completed structure shall be finished according to one of the following methods:

1. One field coat of leafing aluminum paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962-49, Type II, Class B) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or equivalent.

2. One or more field coats of alkyd base enamel pigmented to meet a desired color scheme.

3. Where specific chemicals especially corrosive to aluminum are encountered (such as strong caustic or strong mineral acids), paint systems that provide superior protection against the specific chemicals involved may be used.

H-7: Cleaning and Treatment of Metal Surfaces.—All surfaces to be painted shall be cleaned as follows:

a. Surfaces of metal shall be cleaned immediately before painting, by a method that will remove all dirt, oil, grease, chips, and other foreign substances.

b. Either of the two following methods of cleaning may be used on exposed metal surfaces:

1. Chemical Cleaning: Parts may be immersed in, or swabbed with, a solution of phosphoric acid and organic solvents meeting United States Military Specification MIL-M-10578, after diluting one volume of the concentrate with three volumes of water. The solution temperature shall be between 50°F and 90°F. The solution shall remain in contact with the metal not less than 5 min and shall not be allowed to dry on the surface. Residual solution shall be thoroughly removed by flushing with clear water.

The preceding treatment will provide adequate paint adhesion for most applications. However, if unusual conditions of exposure such as continuous high humidity or highly corrosive atmospheres are anticipated, better paint adhesion will be obtained by following the treatment with application of a commercial chromate conversion solution such as those listed on Military Qualified Products list QPL-5541-16. Such solution shall be applied in accordance with the supplier's instructions.

If it is desirable to apply these treatments in the factory, the stages preceding the conversion chromate application may be modified in accordance with commercial practices for applying chromate conversion coatings.

If treatment is applied at the factory, a shop primer should be applied because handling subsequent to treatment will contaminate the treated surface. If desirable, complete finishing may be performed at the factory following factory pretreatment.

2. Sandblasting: Standard mild sandblasting methods may be used on sections more than 1/8 in. thick.

c. For contacting surfaces only, the metal may be cleaned in accordance with Specification H-7b, or with a solvent such as mineral spirits or benzine.

d. Flame cleaning is not permitted.

PART III. SPECIFICATIONS FOR WELDED STRUCTURES

Section I: Allowable Stresses for Welded Parts.—Welded members are proportioned in accordance with the general rules of Part II, except that it is necessary to reduce the allowable stresses in a "reduced strength zone" extending for a distance of 1 in. on either side of a weld. The 1-in. distance is irrespective of thickness and is measured from the centerline of a butt weld or the heel of a fillet weld.

The allowable stresses for welded cross sections whose entire area lies within 1 in. of a weld are given by Specifications I-1 to I-21 in Tables 6a and 6b. Allowable shear stresses in fillet welds are given by Specifications I-22 to I-24 in Tables 7a and 7b.

I-25: Cross Sections with Part of Area Affected by Heat of Welding.—If less than 15% of the area of a given cross section lies within 1 in. of a weld, the effect of the welds can be neglected and allowable stress for that cross section can be calculated by the formulas in Table 4. If the area of a cross section that lies within 1 in. of a weld is between 15% and 100% of the total area of the cross section, the allowable stress shall be calculated from

$$f_{pw} = f_n - \frac{A_w}{A}\left(f_n - f_w\right) \quad \ldots\ldots\ldots\ldots (10)$$

in which f_{pw} is the allowable stress on cross section, part of whose area lies within 1 in. of a weld, ksi; f_n denotes the allowable stress for same cross section if there were no welds present (see Table 4), ksi; f_w refers to the allowable stress for same cross section if entire area lies within 1 in. of a weld (see Table 6), ksi; A describes the net area of cross section of a tension member or tension flange of a beam, or gross area of cross section of a compression member or compression flange of a beam, in square inches. (A beam flange is considered to consist of that portion of the member farther than 2c/3 from the neutral axis, where c is the distance from the neutral axis to the extreme fiber.); and A_w is the area within area A that lies within 1 in. of weld, in square inches.

I-26: Columns and Single-Web Beams with Welds at Locations Other Than Ends and Cantilever Columns and Single-Web Beams.—The allowable stresses in Specifications I-7 and I-8 apply to members supported at both ends with welds at the ends only (not farther from the supports than 0.05 of the length of the column or beam). For cantilever columns or beams and for columns and beams having welds at locations other than the ends, the allowable stress shall

be determined from the following:

a. Members with welds affecting the entire cross section:

For bridges and similar structures,

$$\left.\begin{array}{ll} f_n > 16.4, & f_w = 10 \\ 16.4 \geq f_n > 3.4, & f_w = \dfrac{13.0}{\sqrt{18.1 - f_n}} \\ f_n \leq 3.4, & f_w = f_n \end{array}\right\} \quad \ldots\ldots\ldots (11a)$$

For buildings and similar structures,

$$\left.\begin{array}{ll} f_n > 18.4, & f_w = 11 \\ 18.4 \geq f_n > 3.8, & f_w = \dfrac{15.5}{\sqrt{20.4 - f_n}} \\ f_n \leq 3.8, & f_w = f_n \end{array}\right\} \quad \ldots\ldots\ldots (11b)$$

b. Members with welds affecting less than the entire cross section: The allowable stress shall be determined from Eq. 10, in which the value of f_w is given by Eqs. 11a or 11b.

Section J: Miscellaneous Design Rules.

J-1: Fatigue.—Fatigue tests indicate that welded members designed in accordance with the requirements of these specifications, and constructed so as to be free from severe re-entrant corners and other unusual stress raisers, will safely withstand at least 20,000 repetitions of maximum live load without fatigue failure regardless of the ratio of minimum to maximum load. Where a greater number of repetitions of some particular loading cycle is expected during the life of the structure, the calculated tensile stresses in welded members shall not exceed the values given in Table 10. Table 10 applies to both of the general types of structures considered in these specifications. When using Table 10, the reversal of load rule in Specification G-1 should be ignored. The final member and connections selected, however, shall be strong enough to satisfy the requirements of G-1. The comments in the listing at the end of Specification G-4 apply to welded as well as riveted or bolted structures.

Section K: Fabrication.

K-1: General.—These specifications are proposed for application to both field and shop welding operations. The general recommendations and regulations shown in the American Welding Society Specifications D2.0-47 "Welded Highway and Railway Bridges" 1947 and D1.0-46 "Code for Arc and Gas Weld-

ing in Building Construction" 1946 apply as well to welded 6061-T6 and 6062-T6 structures. Detail requirements in these specifications apply only to steel structures. Detail requirements for welded alloys 6061-T6 and 6062-T6 are given in the following paragraphs.

K-2: Preparation for Welding.—Dirt, grease, forming or machining lubricants, or any organic materials shall be removed from the areas to be welded by cleaning with a suitable solvent or by vapor degreasing.

Additional operations to remove the oxide coating just prior to welding are required when the inert gas tungsten arc welding method is used. This may be done by etching or by scratch brushing. The oxide coating may not need to be

TABLE 10.—ALLOWABLE TENSILE STRESSES FOR REPEATED LOADS IN WELDED CONSTRUCTION

Number of Repetitions of Load Application	Allowable Stress on Net Section, F_{max}[(a)], ksi	
	Tension on transverse or longitudinal butt welds and tension at locations adjacent to continuous longitudinal fillet welds	Tension at locations adjacent to transverse fillet welds or ends of longitudinal fillet welds, and shear on fillet welds
20,000	F	F
100,000	$F + 0.67 F_{min}$	$0.68F + 0.67 F_{min}$
500,000	$0.73F + 0.67 F_{min}$	$0.40F + 0.67 F_{min}$
1,000,000	$0.67F + 0.67 F_{min}$	$0.34F + 0.67 F_{min}$
2,000,000	$0.65F + 0.67 F_{min}$	$0.29F + 0.67 F_{min}$
10,000,000	$0.64F + 0.67 F_{min}$	$0.23F + 0.67 F_{min}$

F_{max} = allowable maximum tensile stress on net section for repeated loading, ksi, F_{min} = minimum stress on net section during loading cycle, ksi (F_{min} is the smallest tensile stress in a tension-tension cycle or the largest compressive stress in a compression-tension cycle. In the latter case, F_{min} is negative.).

F = allowable stress for nonrepetitive loading, from Table 6a, 6b, 7a, or 7b.

(a) In addition to the limitations given in this table, F_{max} must not exceed F nor the maximum stress permitted by the reversal-of-load rule in Specification G-1.

removed if the welding is performed with the automatic or semiautomatic inert gas shielded metal arc.

Suitable edge preparation to assure 100% penetration in butt welds shall be used. Oxygen cutting shall not be used. Sawing, chipping, machining, shearing, or arc cutting may be used.

K-3: Welding Procedure.—Parts shall be welded with an arc or resistance welding process. No welding process that requires the use of a welding flux shall be used. The filler metal shall be aluminum alloy 5556, 5356, or 4043. Other filler metal alloys may be used provided that they are capable of meeting the qualification test requirements, and result in welds having resistance to corrosion equal to or greater than welds made with filler alloys 5556, 5356, or 4043. Preheating for welding is permissible provided the temperature does not exceed 400°F for a total time of 30 min.

K-4: Qualification of Welding Procedure and Welding Operator.—The welding process and welding operators shall both meet a qualification test. The method of qualification shall be mutually established by the inspecting agency and the contractor or shall conform to the method described in the ASME Boiler and Pressure Vessel Code, Section IX, "Welding Qualifications," Part B, 1962. Aluminum alloy 6061-T6 or 6062-T6 shall be used for the qualification test plates.

The minimum required tensile strength of reduced section specimens in the procedure qualification test is 24 ksi. In addition to the tensile test, side-bend, or face-bend and root-bend tests (either longitudinal or transverse) are required. Operators are qualified on the basis of bend tests and a fillet weld soundness test.

K-5: Rewelding Defects.—Portions of joints that have been rejected on inspection because of defects may be repaired only by rewelding. The defective area shall be removed by chipping or machining. Flame cutting shall not be used. Before rewelding, the joint shall be inspected to assure that all of the defective weld has been removed and that the joint is accessible so that the welding operator can obtain full penetration through the joint.

PART IV. SPECIAL PROVISIONS

Section L.—Single-Web Beams and Girders.—If the designer wishes to compute more precise values of allowable compressive stress for single-web beams and girders, the value of r_y in Specification A-11 may be replaced by an "effective r_y" given by one of the following formulas:

For beam spans subjected to end moment only or to transverse loads applied at the neutral axis of the beam,

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y d}{S_c}}\sqrt{1 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2} \qquad \ldots\ldots (12)$$

For beams subjected to transverse loads applied on the top flange (where the load is free to move laterally with the beam if the beam should buckle),

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y d}{S_c}}\left[-0.5 + \sqrt{1.25 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right] \qquad \ldots (13)$$

For beams subjected to transverse loads applied on the bottom flange (where the load is free to move laterally with the beam if the beam should buckle),

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y d}{S_c}}\left[0.5 + \sqrt{1.25 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right] \qquad \ldots (14)$$

in which C is the coefficient depending on type of loading, as given in Table 11; d is the depth of beam, in inches; I_y refers to the moment of inertia of beam about axis parallel to web, in.^{4}; J denotes the torsion constant of beam, in.^{4} (Values of J are published for many standard shapes (6). Values of J for plates and shapes not published may be calculated by assuming the section to be composed of rectangles and taking the sum of the terms $bt^3/3$ for each rectangle, in which b equals the length and t the thickness of the rectangle, both in inches. The value of J for a built-up member is the sum of the individual values of J for the sections of which it is composed.); and S_c describes the section modulus of beam for compression flange, in cubic inches. For a beam

TABLE 11.—VALUES OF COEFFICIENT C IN FORMULAS FOR ALLOWABLE STRESS IN SINGLE-WEB BEAMS AND GIRDERS

Description of Loading	Value of Coefficient, C
Beam restrained against lateral displacement at both ends of span	
Uniform bending moment, uniform transverse load, or two equal concentrated loads equidistant from the center of the span	1.00
Bending moment varying uniformly from a value of M at one end to β M at the other end	
$\beta = 0.5$	1.14
$\beta = 0$	1.33
$\beta = -0.5$	1.53
$\beta = -1.0$	1.60
Concentrated load at center of span	1.16
Cantilever beams	
Concentrated load at end of span	1.13
Uniform transverse load	1.43

that is unsymmetrical about the horizontal axis, I_y, S_c, and J are calculated as though the beam were symmetrical with both flanges the same as the compression flange of the actual beam.

Section M: Effective Width of Thin Plates in Compression.—Allowable compressive stresses in flat plate elements of columns or beams other than single angles, double angles, tees, or cruciform sections may be permitted to exceed the values given by Specification A-8, A-9, A-15, or A-16, provided that the following steps are taken to insure a suitable margin of safety against the weakening effects of local buckling of plates, legs, and webs:

M-1: Columns.

a. Compute the compressive stress f_c on the flat plate, leg, or web in question, based on the design loads and the gross area, without regard to local

buckling. This stress must be within allowable limits as defined in Specification A-7.

b. Compute the allowable compressive stress, f_1, for the flat plate, leg, or web from Specification A-8 or A-9. If the actual stress, f_c, does not exceed this limiting value, local buckling is not a problem and the full gross area of the plate, leg, or web may be considered effective.

c. If the actual compressive stress exceeds the allowable value found in step b, only a part of the unsupported width of the flat plate, leg, or web shall be included in computing its effective area. The part of the unsupported width of any individual flat plate, leg, or web which may be considered effective shall be found from

$$b_e = b \frac{f_1}{f_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

in which b_e is that part of the unsupported width considered effective, in inches; b denotes the unsupported width, in inches; f_c describes the compressive stress based on gross area from step a, ksi; and f_1 refers to the allowable stress found in step b, ksi.

d. Compute the compressive stress on the effective area. This is simply the axial load divided by the total effective area, which, in turn, is simply the sum of the effective areas of the component parts.

e. The compressive stress on the effective area computed in accordance with step d shall not exceed allowable limits as defined in Specification A-7 for the gross area.

f. Steps c, d, and e provide a suitable factor of safety against collapse of the member as a whole, but do not necessarily provide complete protection against local buckling of individual flat surfaces at the design load. Where local buckling at the design load cannot be tolerated because of appearance, or for other reasons, the computed compressive stress on the gross area, f_c, shall not exceed 1.6 f_1, where f_1 is the compressive stress given in Specification A-8 or A-9 for the b/t ratio in question. Regardless of whether or not this limitation is placed on f_c, the member must still be checked by the method outlined in steps a through e to insure an adequate factor of safety against collapse.

M-2: Beams.—The procedure in Section M-1 can also be applied to beams. In the case of a beam or girder, the stress f_1 shall be determined from Specification A-15 or A-16 and the compressive stress on the effective area shall be determined as follows: Compute the compressive extreme fiber stress f_c for the gross section of the beam or girder and then multiply this value by the ratio of the gross compression flange area to the effective compression flange area, including in each flange area not only the flange proper, but also one-sixth of the area of the web. The stress on the effective area shall not exceed allowable limits as defined in Specifications A-11 to A-14.

PART V. EXPLANATION OF SPECIFICATIONS

Section A: Summary of Allowable Stresses.—The allowable stresses for bridges and similar structures in these specifications represent a factor of

safety of at least 1.85 on minimum yield strength and 2.2 on minimum ultimate strength. These factors of safety are reduced somewhat from those used in the earlier specifications prepared by this committee (1),(2), on the basis of the increased service experience and more extensive test data now available for aluminum alloy structures. The factor of safety of 1.85 on yielding is the same as the factor of safety based on the mill coupon yield strength value used in the AASHO and AREA specifications for steel bridges (3),(4). The factor of safety of 2.2 on ultimate strength is conservative in comparison with the factor of safety on collapse strength of columns and beams incorporated in the AASHO and AREA specifications for steel bridges, on the basis of the analysis of column strength made in the Column Research Council "Guide to Design Criteria for Metal Compression Members," (9) the results of tests on steel beams reported by R. A. Hechtman, F. ASCE, J. S. Hattrup, M. ASCE, E. F. Styer, and J. L. Tiedemann (10), and the mechanical properties of mild steel structural shapes as reported by L. S. Beedle, F. ASCE, and Lambert Tall, A. M. ASCE (11).

The allowable stresses for buildings and similar structures are based on factors of safety of at least 1.65 on minimum yield strength and 1.95 on minimum ultimate strength. These factors of safety are similar to those used in the AISC specifications for steel buildings (5),(9),(10),(11). In the following paragraphs, the factors of safety used to obtain allowable stresses for buildings and similar structures are listed in parentheses.

A-3: Tension in Extreme Fibers of Round or Oval Tubular Beams.—The allowable tensile stress for round or oval tubes subjected to bending is somewhat higher than for structural shapes because analysis and tests have demonstrated that yielding or failure of tubular beams does not occur until the bending moment considerably exceeds the value that would be predicted on the basis of the ordinary flexure formula (12),(13).

A-4: Tension in Extreme Fibers of Rectangular Bars and Plates and Single-Web Shapes Bent About Y-Axis.—As in the case of round tubes, theory and tests have shown that aluminum alloy members of these shapes can undergo bending moments that are considerably higher than those predicted on the basis of the ordinary flexure formula (13),(14),(15).

A-5: Bearing on Rivets and Bolts.—Allowable bearing stresses were determined by applying a factor of safety of 1.85 (or 1.65) to minimum bearing yield strength and 2.2 (or 1.95) to minimum ultimate bearing strength.

A-6: Bearing on Milled Surfaces and Pins.—This allowable stress is equal to two-thirds of the allowable bearing stress on rivets and bolts.

A-7: Compression in Columns.—The formulas in Specification A-7 approximate the tangent modulus column curves with a factor of safety of 2.2 (or 1.95) and with a cutoff at the basic allowable compressive design stress. The tangent modulus column formula is

$$f_C = \frac{\pi^2 E_t}{\left(\frac{k L}{r}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots (16)$$

in which f_C denotes the column strength, ksi; E_t refers to the tangent modulus corresponding to stress f_C, ksi; L is the length of column, in inches; r de-

scribes the least radius of gyration of column, in inches; and k refers to the factor describing the conditions of restraint at the ends of the column.

In the elastic stress range, Eq. 16 is the same as the Euler column formula. In the plastic stress range, Eq. 16 can be approximated by a straight line for aluminum alloys. The applicability of the Euler column formula and the straight line approximation to the tangent modulus curve has been extensively confirmed by tests (16).

The value of the end restraint factor k was considered to be 1.0 for all columns except cantilever columns, for which the value of k was taken to be 2.0. Studies of the effective length of columns in structures have indicated that a k value of 1.0 is conservative for most structural members (17),(18).

A-8 and A-9: Flat Plate Components of Columns.—Allowable stresses for flat plate components of columns and beams were determined by applying a factor of safety of 2.2 (or 1.95) to the strength of plates as given by the formula (20)

$$f_C = \frac{\pi^2 \eta E}{\left(\frac{k' b}{t}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

in which f_C denotes the buckling strength, ksi; E is the modulus of elasticity, ksi; η denotes the modulus reduction factor for buckling of plates in the inelastic stress range; b describes the clear width of plate, in inches; t is the thickness of plate, in inches; and k' refers to a factor depending on the conditions of support at the edges of the plate. It was assumed that the supported edges of plate elements in unwelded columns are simply supported, so that k' = 5.13 for outstanding flanges and 1.63 for plates supported on both edges.

In the inelastic stress range, the factor η was considered to be given by the following formula (20):

$$\eta = \frac{E_s}{E}\left(0.330 + 0.670\sqrt{\frac{1}{4} + \frac{3}{4}\frac{E_t}{E_s}}\right) \quad \ldots\ldots\ldots\ldots (18)$$

in which E_s is the secant modulus, ksi. The curve given by the foregoing formula is approximated by the formulas in Specification A-8.

A-10: Curved Plates and Tubes in Compression.—Allowable compressive stresses in curved plates and tubes are based on the results of tests of round tubes as analyzed by George Gerard and Herbert Becker (21).

A-11: Single-Web Beams.—The allowable compressive stresses in single-web structural shapes and built-up sections bent about the X-axis are based on the application of a factor of safety of 2.2 (or 1.95) to the lateral, torsional buckling strength of beams. The lateral buckling strength of aluminum alloy beams has been investigated experimentally and analytically for a number of different cross sections (19). Allowable stresses in the inelastic stress range for beams are based on the straight line approximation to the tangent modulus buckling curve that is also used for columns. In deriving the allowable stresses for beams, it was assumed that the beam is held in an upright position at the supported ends but the strengthening effect of any restraint against rotation of the flanges at the supports was neglected.

A-12: Round or Oval Tubes in Bending.—Allowable compressive stresses in extreme fibers of round or oval tubes subjected to bending are based on the results of tests of round tubes reported by R. L. Moore, F. ASCE, and M. Holt, M. ASCE (12).

A-13: Solid Rectangular Beams.—The formulas for allowable stresses in rectangular beams are based on the lateral, torsional buckling strength of such beams (14).

A-14: Box Beams.—The formulas for allowable stresses in box beams are based on the lateral, torsional buckling strength of such beams (9a). In deriving these formulas, use was made of the fact that lateral buckling will govern the design only for relatively deep, narrow box beams, and for these members the torsion constant J is roughly proportional to I_y.

A-15 and A-16: Flat Plate Components of Beams.—Outstanding flanges of beams were considered to be partially restrained against rotation at the supported edges ($k' = 4.5$ in Eq. 17) and flat plate compressive elements supported on both edges were considered to be simply supported ($k' = 1.63$ in Eq. 17), based on analysis of the elastic buckling behavior of members with typical proportions, using methods reported by K. Sutter (22).

A-17: Flat Plates with Compression Edge Free and Tension Edge Supported.—The elastic buckling strength of flat plates in bending with the compression edge free and the tension edge supported was determined from Eq. 17 with $k' = 3.5$. The analysis was extended into the plastic stress range on the basis of the treatment of rectangular beams (Specification A-13), because calculations and tests (38) have shown that the apparent stresses (M c/I) at which the yield strength is reached in the outer fiber of sections such as tees and angles are even higher than for rectangular beams.

A-18: Flat Plates in Bending with Both Edges Supported.—The allowable compressive stresses for flat plates with both edges supported were computed on the basis of the formula for the buckling stress with the edges half way between the fixed and simply supported conditions (23). The corresponding value of k' in Eq. 17 is 0.60. A factor of safety of 1.35 (or 1.2) was applied to the buckling strength in this case, because tests have demonstrated that the stresses in plates of this type can appreciably exceed the calculated buckling stress without affecting the behavior of the beam (23), (24).

A-19: Flat Plates in Bending with Horizontal Stiffener.—The allowable compressive stresses in webs with a horizontal stiffener were determined by applying a factor of safety of 1.35 (or 1.2) to the buckling stress for plates with simple support at the edges and at the stiffener. The value of k' in Eq. 17 for this case is 0.29, based on calculations by C. Dubas, as reported by Friedrich Bleich (17a).

A-20: Shear in Unstiffened Flat Webs.—Allowable shear stresses in unstiffened flat webs were obtained by applying a factor of safety of 2.2 (or 1.95) to the calculated buckling strength for a web with partial restraint against rotation at the attachment to the flanges (41), (42), giving a value of k' in Eq. 17 of 1.25. In the plastic stress range, the plastic reduction factor η was considered to be given by Eq. 18 with the exception that the values of the tangent modulus and secant modulus corresponding to a given shear stress were considered to be the same as the values of the tangent modulus and secant modulus corresponding to a compressive stress equal to $\sqrt{3}$ times the shear stress (41).

A-21: Shear in Stiffened Flat Webs.—Allowable stresses for stiffened flat webs were computed on the basis of assumptions similar to those used for unstiffened webs, except that a factor of safety of 1.35 (or 1.2) was applied to the buckling strength of stiffened beam webs, because tests have demonstrated that shear stresses in such webs can considerably exceed the calculated buckling strength without appreciably affecting the behavior of the beam (42).

A-22 and A-23: Allowable Shear in Rivets.—The minimum shear strength of rivets was considered to be equal to the typical strength divided by 1.15. The factors of safety applied to minimum rivet shear strengths in order to obtain allowable shear stresses were 20% higher than the basic factors of safety applied to minimum strength values elsewhere in these specifications.

A-24: Allowable Shear and Tension in Bolts.—The factors of safety applied to minimum shear strength and minimum tensile strength of 2024-T4 bolts are 20% higher than the basic factors of safety on minimum ultimate strength used elsewhere in these specifications.

A-25: Allowable Shear in Pins.—It is not anticipated that any wide use of pins will be made in aluminum alloy structures, but it is assumed that where they are used, they will be the same material as the rest of the structure and will probably be obtained in the form of rolled rod. The minimum shear strength of 6061-T6 rolled rod (25 ksi) was divided by a factor of safety of 2.2.

Section B: Column Design.

B-7: Combined Compression and Bending.—Eq. 1 is based on an interaction formula that gives good agreement with the results of tests on aluminum members subjected to combined compressive end load and uniform bending moment (26). The formula is applicable to members in which the bending is applied about either the strong or the weak axis and to members in which the strength is controlled by either overall or local buckling.

Eq. 1 becomes ultraconservative for members in which the bending moment at the center is appreciably less than the maximum bending moment in the column. For such members, Eq. 2 or Eq. 3 is satisfactory.

B-8: Transverse Shear in Columns.—Eq. 4 for transverse shear in columns is similar to an equation used in the German Specifications (44). This equation agrees well with the more complicated expression, based on the work of E. C. Hartmann, F. ASCE (27), which was used in this committee's earlier specifications.

Section D: Design of Plates, Legs, and Webs in Compression.

D-4: Stiffeners for Flat Plates in Compression.—Eqs. 5a and 5b for required size of stiffening lips or bulbs are based on theoretical and experimental studies reported by M. S. Anderson (35) and by P. S. Bulson (36).

Section E: Plate Girder Design.

E-8: Size of Vertical Stiffeners to Resist Shear Buckling.—Eqs. 9a and 9b are based on the results of tests of aluminum girders reported by Moore (40) and the theoretical analysis of Manual Stein and R. W. Fralich (29). Stiffness values calculated from Eqs. 9a and 9b are approximately the same as the values given by the more complex expression used in this committee's previous specifications.

E-9: Vertical Stiffeners at Points of Bearing.—Eq. 10 requires that the moment of inertia of a stiffener at a point of bearing should be equal to the sum of the moment of inertia required to resist the tendency of the web to buckle and the moment of inertia required for the stiffener to carry the bearing load as a column with length equal to the height of the web.

E-10: Horizontal Stiffeners.—Eq. 11, for the moment of inertia of horizontal stiffeners, is based on the theoretical work of C. Dubas, reported by Bleich (17), and on the experiments reported by C. E. L. Massonnet, F. ASCE (37), and by K. C. Rockey (25).

Section F: Riveted and Bolted Connections.

F-10: Stitch Rivets and Bolts.—The requirements for spacing of stitch rivets are based on conventional practices that have been found to give satisfactory results for thin-gage construction as well as for the thicker gages more commonly used in heavy-duty structures.

Section G: Miscellaneous Design Rules.

G-4: Fatigue.—The allowable stresses for repeated loading, given in Table 9, are based on the results of fatigue tests of riveted joints as reported by M. Holt, I. D. Eaton and R. B. Matthiesen (30). The factors of safety that have been applied to the test results are 1.35 and 1.2 for bridges and buildings, respectively.

Section I: Allowable Stresses for Welded Parts.—The allowable stresses for cross sections near welds given in Section I are based on the same principles as are the allowable stresses in Section A, with the exception that some of the allowable stresses for cross sections near welds are reduced in order

TABLE 12.—MINIMUM SHEAR STRENGTH OF FILLET WELDS[a]

Filler alloy	Transverse shear in single fillet welds and longitudinal shear	Transverse shear in double fillet welds
5556	19.5	30
5356	17	26
4043	12	16

[a] In ksi.

to account for the softening effect of the heat of welding. The basic strength values used in obtaining the allowable stresses in Tables 7a and 7b are listed in Table 1. The values of minimum shear strength of fillet welds listed in Table 12 were used in conjunction with the shear strength of the parent metal in the heat affected zone as a basis for the values of allowable shear stress in fillet welds given in Tables 7a and 7b.

In obtaining the allowable tensile stress on welds, the tensile strength value of 24 ksi for material affected by the heat of welding was multiplied by a factor of 0.9, and the resulting stress was divided by a factor of safety of 2.2 (or 1.95). The yield strength was divided by a factor of safety of 1.85 (or 1.65). The factor 0.9 was used to take account of the fact that, for welds that receive only visual inspection, the minimum strength value in Table 1 can probably not be considered to have the same reliability as the minimum mechanical properties of the parent metal, even though the weld strength value is based on ASME weld qualification test requirements (31) and on extensive tests (32). The factors of safety applied to minimum fillet weld strengths in order to obtain allowable stresses were 20% greater than the basic factors of safety applied to ultimate strength elsewhere in these specifications. Background in-

formation on the provisions of Section I, including the use of Eq. 12, can be found in the literature (33), (34).

Tests and analysis of welded aluminum columns (34) have shown that, for simply supported columns (k = 1.0), welds at the ends have little effect on the buckling strength in the range of slenderness ratios where design is controlled by buckling rather than by yielding. In deriving the allowable stresses in Specifications I-7, I-11, and I-14, therefore, end welds were not considered to affect the buckling strength. Similarly, it was considered that welds will not seriously affect the buckling strength of flat plates supported on both edges, as in the cases covered by Specifications I-9, I-16, and I-18 to I-21. However, the allowable stresses in Specifications I-8, I-10, I-12, I-13, I-15 and I-17 are based on the conservative assumption that the buckling strengths of the members covered by these specifications are controlled by the mechanical properties of the heat-affected material immediately adjacent to the weld.

In obtaining formulas for allowable stress based on local buckling of flat plate elements, the values of k' in Eq. 17 were assumed to be the same as for unwelded plates, except that for buckling in the inelastic stress range in the case of Specifications I-8 and I-15, the values of k' were considered to be halfway between the values used for unwelded plates and the values that would apply to plates with fixed edges. This assumption was made to take into account the restraining effect of the weld bead and the surrounding metal that is not affected by the heat of welding.

Section J: Miscellaneous Design Rules.

J-1: Fatigue.—The allowable stresses for repeated loadings, given in Table 10, are based on the results of fatigue tests of welded joints (7), (8). The factors of safety that have been applied to the test results are 1.35 and 1.2 for bridge structures and building structures, respectively.

Section K: Fabrication.

K-3: Welding Procedure.—The use of alloy 5556 or 5356 as a filler metal produces welds of greater strength and ductility than are generally obtained with alloy 4043. Welds in highly restricted locations may sometimes show cracking when 5556 or 5356 filler metal is used. If this condition cannot be eliminated by adjustments of procedure or fixtures, the cracking tendency can be reduced by using 4043 filler metal. As indicated by the notes in Tables 6a and 6b, basic allowable stresses must be reduced 20% if Alloy 4043 filler wire is used to weld metal more than 3/8 in. thick.

K-4: Qualification of Welding Procedure and Welding Operator.—The minimum requirement of 24 ksi for tensile strength of a reduced-section specimen used in a welding qualification test is the same as the minimum requirement in the ASME Boiler and Pressure Vessel Code (31).

Section L: Single-Web Beams and Girders.—Eqs. 14a to 14c are derived from the general equation for elastic buckling strength of beams (19) by making the approximation that the effects of lack of symmetry of the cross section about an axis perpendicular to the web can be taken into account by calculating J, I_y, and S_c as though both flanges were the same as the compression flange. This assumption is justified by Figs. 5 to 8 of J. W. Clark, M. ASCE, and H. N. Hill, F. ASCE (19), which show that the lateral buckling stress for an I-section is not greatly affected by changes in the size of the tension flange. It was also assumed that the formula for torsion bending constant for I-sections ($C_s = d^2 I_y/4$) applies approximately to all sections (39).

Section M: Effective Width of Thin Plates in Compression.

M-1 and M-2: Effective Width of Thin Plates in Compression.—When a flat plate, leg, or web is built in along one or both edges to other parts of a compression member which offer partial edge restraint, the local buckling of the plate, leg, or web does not precipitate collapse of the member as a whole as it probably would in the case of a single-angle strut. For this reason, it is proper to permit a decreased factor of safety against local buckling in such cases if suitable precautions are taken to avoid collapse. Step c of this specification provides a simple method for accomplishing this result by introducing the well-known "effective width" concept. After a plate, leg, or web buckles, a part of its area is considered to be ineffective in supporting load, whereas a strip along each supported edge is considered still fully effective in working with the supporting material to which it is attached. The formula (Eq. 15) for effective width used in step c is generally more conservative than other accepted methods of computing effective width (28).

The limitation placed on the value of f_c in Step f is intended to provide a small factor of safety against local buckling at the design load.

This report is respectfully submitted by the Task Committee on Lightweight Alloys, Committee on Metals, Structural Division:

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APPENDIX I.—BIBLIOGRAPHY ON STRUCTURES OF ALUMINUM ALLOYS 6061-T6 AND 6062-T6

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APPENDIX II.

Allowable stresses for 6061-T6 and 6062-T6 buildings and other structures to which allowable stresses for buildings are normally applied (Tables 4b, 5b, 6b, and 7b).

TABLE 5b.—ALLOWABLE SHEAR STRESSES IN RIVETS AND BOLTS (BUILDING STRUCTURES)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear area	Tension on root area
A-22b	6061-T6 rivets, cold driven	11	--
A-23b	6061-T43 rivets, driven at temperatures of from 990°F to 1,050°F	9	--
A-24b	2024-T4 bolts	16[a]	26
A-25b	6061-T6 pins	11	--

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

TABLE 7b.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS (BUILDING STRUCTURES)

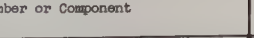
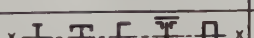
Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse Shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-22b	5556	8.5	9[c]
I-23b	5356	7	9[c]
I-24b	4043	5	7

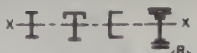
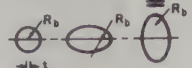
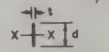
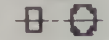
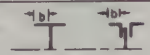
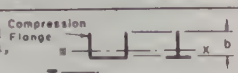
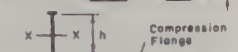
[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

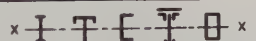
TABLE 4b.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6061-T6 AND 6062-T6 BUILDING STRUCTURES NONWELDED)

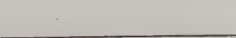
Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1b	Any tension member	19				
TENSION in extreme fibers of beams, net section		A-2b	Structural shapes, rectangular tubes, built-up members bent about X-axis 	19				
		A-3b	Round or oval tubes	24				
		A-4b	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis 	26				
BEARING		A-5b	On rivets and bolts	34(a)				
		A-6b	On milled surfaces and pins	23				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs A-8b to A-10b)	A-7b	Columns	19	$\frac{L}{r} = 10$	$20.4 - 0.136\frac{L}{r}$	$\frac{L}{r} = 67$	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7b)	A-8b	Outstanding flanges and legs	19	$\frac{b}{t} = 5.6$	$23.7 - 0.86\frac{b}{t}$	$\frac{b}{t} = 12$	$\frac{1,940}{(b/t)^2}$
		A-9b	Flat plates with both edges supported	19	$\frac{b}{t} = 17$	$23.7 - 0.27\frac{b}{t}$	$\frac{b}{t} = 38$	$\frac{19,200}{(b/t)^2}$
		A-10b	Curved plates supported on both edges and walls of round or oval tubes	19	$\frac{R}{t} = 22$	$22.6 - 0.76\sqrt{\frac{R}{t}}$	$\frac{R}{t} = 125$	- - - -

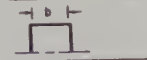
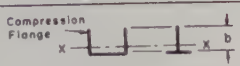
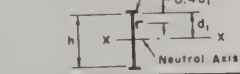
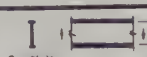
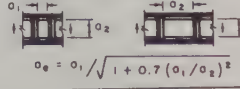
	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15b to A-19b)	A-11b	Single-web structural shapes and built-up sections bent about X-axis		19	$\frac{L_b}{r_y} = 12$	$20.4 - 0.113\frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 81$	$\frac{74,000}{(L_b/r_y)^2}$
		A-12b	Round or oval tubes		24	$\frac{R_b}{t} = 19$	$28.2 - 0.22\frac{R_b}{t}$	$\frac{R_b}{t} = 60$	- - - -
		A-13b	Solid rectangular beams bent about X-axis		26	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 11$	$34.9 - 0.80\frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 29$	$\frac{9,900}{(\frac{d}{t})^2\frac{L_b}{d}}$
		A-14b	Rectangular tubes and box sections		19	$\frac{L_b^3 c}{I_y} = 40$	$20.4 - 0.22\sqrt{\frac{L_b^3 c}{I_y}}$	$\frac{L_b^3 c}{I_y} = 1810$	$\frac{20,000}{L_b^3 c/I_y}$
COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs A-11b to A-14b)	A-15b	Flat plates with one edge free and one edge supported		19	$\frac{b}{t} = 6.2$	$23.7 - 0.76\frac{b}{t}$	$\frac{b}{t} = 14$	$\frac{2,500}{(b/t)^2}$
		A-16b	Flat plates with both edges supported		19	$\frac{b}{t} = 17$	$23.7 - 0.27\frac{b}{t}$	$\frac{b}{t} = 38$	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11b to A-14b)	A-17b	Flat plates with compression edge free and tension edge supported, bent about X-axis		26	$\frac{b}{t} = 7.3$	$34.9 - 1.24\frac{b}{t}$	$\frac{b}{t} = 19$	$\frac{4,200}{(b/t)^2}$
		A-18b	Flat plates with both edges supported, bent about X-axis		19	- - - -	19	$\frac{h}{t} = 110$	$\frac{230,000}{(h/t)^2}$
		A-19b	Flat plates with both edges supported, bent about X-axis with horizontal stiffener		19	- - - -	19	$\frac{h}{t} = 228$	$\frac{990,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-20b	Unstiffened flat webs		12	h/t = 18	13.7 - 0.092 $\frac{h}{t}$	$\frac{h}{t} = 66$	$\frac{33,000}{(h/t)^2}$
		A-21b	Stiffened flat webs		12	- - - -	12	$\frac{a_e}{t} = 66$	$\frac{53,000}{(a_e/t)^2}$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or greater. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

TABLE 6b.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6061-T6 AND 6062-T6 BUILDING STRUCTURES WELDED)

Type of Stress	Specification No.	Type of Member or Component	Allowable Stress, ksi
TENSION, axial, net section	I-1b	Any tension member	11(b)
TENSION in extreme fibers of beams, net section	I-2b	Structural shapes, rectangular tubes, built-up members bent about X-axis 	11(b)
	I-3b	Round or oval tubes	13(b)
	I-4b	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	13(b)
BEARING	I-5b	On rivets and bolts	18(b)(d)
	I-6b	On milled surfaces and pins	12(b)

				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION,(a) gross section (Also see Specs I-8b to I-10b)	I-7b	Columns(a)	11(b)	- - - -	11(b)	$\frac{L}{r} = 68$(c)	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7b)	I-8b	Outstanding flanges and legs	11(b)	$\frac{b}{t} = 4.9$(c)	$\frac{24.4}{\sqrt{b/t}}$	$\frac{b}{t} = 19$	$\frac{1,940}{(b/t)^2}$
		I-9b	Flat plates with both edges supported 	11(b)	- - - -	11(b)	$\frac{b}{t} = 44$(c)	$\frac{19,200}{(b/t)^2}$
		I-10b	Curved plates supported on both edges and walls of round or oval tubes	11(b)	$\frac{R}{t} = 14$(c)	$\frac{21.3}{(R/t)^{1/4}}$	$\frac{R}{t} = 200$	- - - -
COMPRESSION in Members Subjected	COMPRESSION(a) in extreme fibers of beams, gross section (Also see Specs. I-15b to I-19b)	I-11b	Single-web structural shapes and built-up sections bent about X-axis(a)	11(b)	- - - -	11(b)	$\frac{L_b}{r_y} = 82$(c)	$\frac{74,000}{(L_b/r_y)^2}$
		I-12b	Round or oval tubes	13(b)	$\frac{R_b}{t} = 13$(c)	$\frac{24.7}{(R_b/t)^{1/4}}$	$\frac{R_b}{t} = 135$	- - - -
		I-13b	Solid rectangular beams bent about X-axis	13(b)	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 11$(c)	$\frac{42.3}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 38$	$\frac{9,900}{(\frac{d}{t})^2 \frac{L_b}{d}}$
		I-14b	Rectangular tubes and box sections(a)	11(b)	- - - -	11(b)	$\frac{L_b S_c}{I_y} = 1820$(c)	$\frac{20,000}{L_b S_c / I_y}$

to Bending, Gross Section	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11b to I-14b)	I-15b	Flat plates with one edge free and one edge supported		11(b)	$\frac{b}{t}$ = 5.3(c)	$\frac{25.4}{\sqrt{b/t}}$	$\frac{b}{t}$ = 21	$\frac{2,500}{(b/t)^2}$
		I-16b	Flat plates with both edges supported		11(b)	- - - -	11(b)	$\frac{b}{t}$ = 44(c)	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11b to I-14b)	I-17b	Flat plates with compression edge free and tension edge supported, bent about X-axis		13(b)	$\frac{b}{t}$ = 6.8(c)	$\frac{34.0}{\sqrt{b/t}}$	$\frac{b}{t}$ = 95	$\frac{4,200}{(b/t)^2}$
		I-18b	Flat plates with both edges supported, bent about X-axis		11(b)	- - - -	11(b)	$\frac{h}{t}$ = 144(c)	$\frac{230,000}{(h/t)^2}$
		I-19b	Flat plates with both edges supported, bent about X-axis with horizontal stiffener		11(b)	- - - -	11(b)	$\frac{h}{t}$ = 300(c)	$\frac{990,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-20b	Unstiffened flat webs		7(b)	- - - -	7(b)	$\frac{h}{t}$ = 69(c)	$\frac{33,000}{(h/t)^2}$
		I-21b	Stiffened flat webs		7(b)	- - - -	7(b)	$\frac{a_e}{t}$ = 87(c)	$\frac{53,000}{(a_e/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification I-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy and to material 3/8-in. or less in thickness welded with 4043 filler alloy. For thicker material welded with 4043 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a superscript apply to material welded with either 4043, 5556 or 5356 filler alloy.

(c) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy and to material 3/8-in. or less in thickness welded with 4043 filler alloy. For thicker material welded with 4043 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in Note (b) above.

(d) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter)

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SUGGESTED SPECIFICATIONS FOR STRUCTURES OF ALUMINUM ALLOY 6063-T5 AND 6063-T6

Report of the Task Committee on Lightweight Alloys
Committee on Metals, Structural Division

COMMITTEE REPORT

The Task Committee on Lightweight Alloys (formerly the Committee on Design in Lightweight Structural Alloys) has prepared two suggested specifications for the design of structures of aluminum alloys. The first of these is for 6061-T6 and 6062-T6 alloys (Proc. Paper 3341) and supersedes the previous specifications (1), (2).[1] The second specification is for alloy 6063-T5 and 6063-T6 (Proc. Paper 3342). The task committee hopes that those who have constructive comments on, or criticism of, the suggested specifications will submit them to the Society.

POLICY OF THE STRUCTURAL DIVISION, ASCE, RELATIVE TO STRUCTURAL SPECIFICATIONS

(Adopted by the Executive Committee, Structural Division, on May 26, 1962)

No specification shall be issued in the name of, nor be endorsed by, the Structural Division of ASCE.

Specifications may be prepared by Task Committees of the Structural Division, ASCE, working alone or jointly with other groups. Such specifications may be submitted as committee reports, through the Executive Committee of the Division, for publication in the structural division Journal.

Note.—Discussion open until May 1, 1963. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. ST6, December, 1962.

[1] Numerals in parentheses refer to corresponding items in Appendix I.

The Structural Division Executive Committee requests that any committee report that takes the form of a specification, and is written in the usual terse specification style, be accompanied by a commentary or discussion supporting and explaining the specification. The Executive Committee will submit such a report for publication, after the necessary review and approval.

It is the desire and intent of the Structural Division Executive Committee that the best interests of the members of ASCE and the engineering profession be served. Where this is best accomplished by publication and open discussion of design specifications in the Division Journal, this will be done. The Committee feels that no useful purpose will be served by ASCE endorsement of specifications; however, constructive criticism and discussion will add materially to the understanding and improvement of specifications.

SYNOPSIS

These specifications cover the allowable stresses, design rules, and fabrication procedures for structures built of the aluminum alloy designated as 6063-T5 and 6063-T6. The designations -T5 and -T6 refer to different heat treatments which result in different mechanical properties. For each of these two tempers, two sets of allowable stresses are provided: One Set is for bridges and other structures to which allowable stresses for bridges are normally applied: the other set is for buildings and other structures to which allowable stresses for buildings are normally applied. For 6063-T6, the basic allowable tensile working stresses are 13.5 ksi for bridges and 15 ksi for buildings, based on a minimum yield strength of 25 ksi and a minimum tensile strength of 30 ksi. For 6063-T5, the basic allowable tensile working stresses are 8.5 ksi for bridges and 9.5 ksi for buildings, based on a minimum yield strength of 16 ksi and a minimum tensile strength of 22 ksi.

PART I.—GENERAL

Introduction.—These specifications cover the allowable stresses, the design rules, and the fabrication procedures for an aluminum alloy which may be used for structural purposes where a high degree of resistance to corrosion and moderate strength are desired. This alloy is often used in applications where the design of the member is governed by limits on permissible deflections or slenderness ratios rather than the strength of the material. In the preparation of these specifications, the committee has made use of the available theoretical and experimental work relating to this subject and particularly to the committee's previously published specifications (1), (2).

These specifications are confined to allowable stresses, design rules, and fabrication. No attempt has been made to cover the loading, erection, inspec-

tion, or nontechnical provisions included in many specifications, since such provisions are fairly well established in current good structural practice. Furthermore, no attempt has been made to include design rules which cover every detail of construction but rather those that are different from steel practice or that are needed for the sake of completeness. It is intended, of course, that structures built under these specifications will be designed, constructed, and erected by following the current good practice already well established for metal structures, except as modified herein.

It is believed that the designer can make more efficient use of a set of specifications if he knows the basis for its various provisions. For this reason, Part V, "Explanation of Specifications," has been added. Part V contains background information and references concerning those paragraphs of the specifications for which some explanation seems required.

When the abbreviation "ksi" is used in these specifications it denotes "kips per square inch" or "thousands of pounds per square inch."

Material.—The principal material considered in these specifications is an aluminum alloy having the following nominal chemical composition:

Composition	Percentage By weight
Silicon	0.4
Magnesium	0.7
Others	1.0
Aluminum	97.9
Total	100.0

This material is covered by the following American Society for Testing and Materials (ASTM) specifications:

Product	ASTM Specification No.
Drawn Seamless Tubes	B210-62 (6063-T6)
Extruded Bars, Rods, and Shapes	B221-62 (6063-T5 and -T6)
Extruded Tubes	B235-62 (6063-T5 and -T6)
Pipe	B241-62 (6063-T5 and -T6)

The -T5 temper is attained by artificial aging after extrusion. The -T6 temper is attained by solution heat treatment followed by artificial aging. The specified minimum tensile strength and tensile yield strength for 6063-T6 are 30 ksi and 25 ksi, respectively, for all products except drawn tube. The values for drawn tube are 33 ksi and 28 ksi, respectively. For 6063-T5, the specified minimum tensile strength is 22 ksi and the specified minimum yield strength is 16 ksi. The minimum mechanical properties that have been used as a basis for the selection of allowable stresses in these specifications are listed in Table 1.

Materials for rivets, bolts, nuts, washers, and welding rods and electrodes are covered by the ASTM specifications noted in Table 2.

TABLE 1.—BASIC STRENGTH DATA[a]

	Unaffected Parent Material		Material Affected by Heat of Welding,
	6063-T5	6063-T6	6063-T5 and 6063-T6
Tensile strength	22	30	17[b]
Tensile yield strength	16	25	11[c]
Compressive yield strength	16	25	11[c]
Shear strength	13	19	11
Shear yield strength	9	14	6.5
Bearing strength	46	63	36
Bearing yield strength	25	40	17

[a] Minimum strength values for Alloy 6063-T5 and 6063-T6, ksi (thickness 0.500 in. and under).

[b] ASME weld qualification test value for tensile strength across a butt weld.

[c] These are expected minimum values of the yield strength across a butt weld, corresponding to 0.2% offset on a 10-in. gage length.

TABLE 2.—APPLICABLE ASTM SPECIFICATIONS

Product	Alloy	ASTM Specification for material from which product is made
Rivets	6061-T6 or 6061-T4[(a)]	B316-62 - rivet and cold heading wire and rods [(b)]
Bolts	2024-T4	B316-62 - rivet and cold heading wire and rods [(b)]
Nuts	6061-T6 or 6262-T9	B211-62 - bars, rods and wire, or B316-62 - rivet and cold heading wire and rods [(b)]
Washers	Alclad 2024-T3 or -T4	B209-62 - sheet and plate
Welding rods and electrodes	ER4043 or ER5356	B285-62T - welding rods and bare electrodes

[a] ASTM B316-62 includes mechanical property specifications for 6061-T6 but not 6061-T4. The heat treatment for the latter is the same as the former except that the artificial aging is omitted.

[b] ASTM B316-62 covers rods up to 0.615 in. in diameter. Rods with diameters from 0.615 to 1.000 in. are supplied with the same mechanical property limits and tolerances on diameter (+0.003 in., -0.001 in.) that apply to 0.615-in. rod in ASTM B316-62.

Following are typical values of other physical properties of this alloy:

Properties	Numerical Values
Modulus of elasticity, ksi	10,000
Modulus of elasticity in shear, ksi	3,800
Poisson's ratio	1/3
Coefficient of expansion, per degree Fahrenheit	0.000012
Weight, in pounds per cubic inch	0.098

Alloy 6063-T5 and 6063-T6 is the one principally considered in the preparation of these specifications and the one to which the allowable stresses for parts other than bolts apply. However, these specifications may be applied to structures built of other suitable aluminum alloys, provided such alloys meet the specified strengths and elongations for either 6063-T5 or 6063-T6, listed in the ASTM Specifications mentioned in the first paragraph of this section.

TABLE 3.—ALLOYS TO BE USED FOR RIVETS

Designation before driving	Driving procedure	Designation after driving	Typical shear strength[a]
6061-T4	Hot, 990°F to 1050°F	6061-T43	24
6053-T61	Cold, as received	6053-T61	23

[a] Typical ultimate shear strength of the driven rivet, ksi.

Whether or not such other alloys need paint protection will depend on whether they are as resistant to corrosion as 6063-T5 and 6063-T6. The sections of this specification dealing with welding should not be applied to other alloys unless it has been clearly demonstrated that such alloys are suitable for welding.

Rivets used in fabricating structures designed in accordance with these specifications shall be of aluminum alloy and may be either cold driven or hot driven. The alloys used are indicated in Table 3.

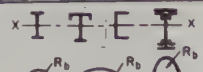
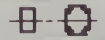
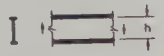
Aluminum bolts used in structures designed in accordance with these specifications shall be of alloy 2024-T4. Such bolts have an expected minimum tensile and shear strength of 62 ksi and 37 ksi, respectively.

PART II. SPECIFICATIONS FOR RIVETED AND BOLTED STRUCTURES

Section A: Summary of Allowable Stresses.—The allowable stresses to be used in proportioning the parts of a structure shall be determined from Tables 4a to 7a, 4b to 7b, 4c to 7c and 4d to 7d. The allowable stresses in Tables 4a

TABLE 4a.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES OR IN WELDED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6063-T6 BRIDGE STRUCTURES NONWELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1a	Any tension member	13.5				
TENSION in extreme fibers of beams, net section		A-2a	Structural shapes, rectangular tubes, built-up members bent about X-axis	13.5				
		A-3a	Round or oval tubes	15				
		A-4a	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	17				
BEARING		A-5a	On rivets and bolts	21.5(a)				
		A-6a	On milled surfaces and pins	14.5				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs. A-8a to A-10a)	A-7a	Columns	12	$L/r = 10$	$12.7 - 0.071\ L/r$	$L/r = 81$	$\frac{45,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7a)	A-8a	Outstanding flanges and legs	12	$b/t = 6.0$	$14.7 - 0.45\ b/t$	$b/t = 15$	$\frac{1,720}{(b/t)^2}$
		A-9a	Flat plates with both edges supported	12	$b/t = 19$	$14.7 - 0.141\ b/t$	$b/t = 45$	$\frac{17,000}{(b/t)^2}$
		A-10a	Curved plates supported on both edges and walls of round or oval tubes	12	$R/t = 15$	$13.6 - 0.41\sqrt{R/t}$	$R/t = 140$	- - - -

	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15a to A-18a)	A-11a	Single-web structural shapes and built-up sections bent about X-axis		12	$L_b/r_y = 12$	$12.7 - 0.059\ L_b/r_y$	$L_b/r_y = 96$	$\frac{65,000}{(L_b/r_y)^2}$
		A-12a	Round or oval tubes		15	$R_b/t = 16$	$15.9 - 0.058\ R_b/t$	$R_b/t = 120$	- - - -
		A-13a	Solid rectangular beams bent about X-axis		17	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 12$	$22.0 - 0.42\ \frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 33$	$\frac{8,800}{(d/t)^2 L_b/d}$
		A-14a	Rectangular tubes and box sections		12	$\frac{L_b S_c}{I_y} = 38$	$12.7 - 0.114\sqrt{\frac{L_b S_c}{I_y}}$	$\frac{L_b S_c}{I_y} = 2540$	$\frac{17,700}{L_b S_c / I_y}$
COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. A-11a to A-14a)	A-15a	Flat plates with one edge free and one edge supported		12	$b/t = 6.8$	$14.7 - 0.40\ b/t$	$b/t = 17$	$\frac{2,240}{(b/t)^2}$
		A-16a	Flat plates with both edges supported		12	$b/t = 19$	$14.7 - 0.141\ b/t$	$b/t = 45$	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11a to A-14a)	A-17a	Flat plates with compression edge free and tension edge supported, bent about X-axis		17	$b/t = 7.5$	$22.0 - 0.66\ b/t$	$b/t = 22$	$\frac{3,700}{(b/t)^2}$
		A-18a	Flat plates with both edges supported, bent about X-axis		12	- - - -	12	$h/t = 131$	$\frac{205,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-19a	Unstiffened flat webs		7.5	$h/t = 20$	$8.5 - 0.049\ h/t$	$h/t = 78$	$\frac{29,000}{(h/t)^2}$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter)

through 7a are intended for application to 6063-T6 in bridge structures and other structures to which specifications similar to the AASHO (5) and AREA (4) Specifications for Steel Bridges are applied. These specifications are designated by the numbers A-1a to A-22a and I-1a to I-21a. Allowable stresses for 6063-T5 in bridge structures are covered by Specifications A-1b to A-22b and I-1b to I-21b in Tables 4b to 7b.

Allowable stresses for buildings and other structures to which specifications similar to the AISC specifications for steel buildings are applied are presented in Tables 4c to 7c and 4d to 7d in Appendix II at the end of these specifications. Specifications A-1c to A-22c and I-1c to I-21c in Tables 4c to 7c apply to alloy 6063-T6, and Specifications A-1d to A-22d and I-1d to I-21d apply to 6063-T5. In subsequent sections of these specifications, where reference is made to a specification number such as "A-1," this number is intended to apply to either A-1a, A-1b, A-1c, or A-1d.

TABLE 5a.—ALLOWABLE STRESSES IN RIVETS AND BOLTS (BRIDGE STRUCTURES OF 6063-T6)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear area	Tension on root area
A-20a	6053-T61	7.5	--
A-21a	6061-T43 rivets, driven at temperatures of from 990°F to 1050°F	8	--
A-22a	2024-T4 bolts	14[a]	23

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

In applications where it is conventional practice to increase allowable stresses for certain types of loads, such as wind loads, the allowable stresses in these specifications should be increased in the same proportion as are the allowable stresses in accepted specifications for steel structures.

The terms appearing in the formulas in Tables 4a to 4d and 6a to 6d are defined as follows:

b = clear width of outstanding flange or of flat plate supported on both unloaded edges, in inches;

d = depth of beam, in inches;

d_1 = distance from toe of compression flange to neutral axis, in inches;

h = clear height of shear web, in inches;

I_y = moment of inertia of a beam (about axis parallel to web), in.^{4};

L = length of compression member between points of lateral support or twice the length of a cantilever column (except where analysis shows that a shorter length can be used), in inches;

L_b = length of beam between points at which the compression flange is supported against lateral movement or length of cantilever beam from free end to point at which the compression flange is supported against lateral movement, in inches;

R = outside radius of round tube or maximum outside radius for an oval tube, in inches;

R_b = outside radius of a round tube in bending or outside radius at the location of the critical compressive stress for an oval tube in bending, in inches. (The location of the critical compressive stress is at the extreme fiber for an oval tube bent about the major axis. For an oval tube bent about the minor axis, the location of the critical stress can be determined by calculating the allowable stress at several points using the formulas of Specification A-12, with R_b equal to the outside radius at each point. Bending moments corresponding to the allowable stresses at the various points are calculated, and the point resulting in the smallest bending moment is the location of the critical compressive stress.);

r = least radius of gyration of a column, in inches;

r_y = radius of gyration of a beam (about axis parallel to web), in inches. (For beams that are unsymmetrical about the horizontal axis, r_y should be calculated as though both flanges were the same as the compression flange.);

S_c = section modulus of a beam (compression side), in cubic inches; and

t = thickness of flange, plate, web or tube, in inches. (For tapered flanges, t is the average thickness.)

Section B: Column Design.

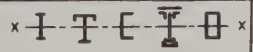
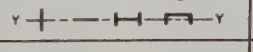
B-1: Allowable Compressive Stress in Columns.—The allowable compressive stress on the gross section of axially loaded columns shall be determined from the formulas in Specification A-7.

Columns having cross sections involving webs and outstanding legs of such proportions that local buckling may control the design shall be checked by Specifications A-8 to A-10 or by the method outlined in Part IV, Section M.

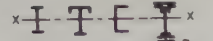
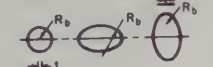
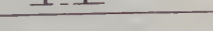
Open section members that are unsymmetrical about one or both principal axes may be subject to failure by combined torsion and flexure. For single and double angles and tee sections, Specification A-8 provides an adequate factor of safety against this type of failure. Other unsymmetrical, open shapes, such as channels, lipped angles, or hat shapes, shall not be used as columns unless a special analysis is made of the resistance to buckling by combined torsion and flexure (17), (37).

B-2: Columns with Slenderness Ratio Exceeding 120.—Because long columns are relatively flexible, they may be appreciably weakened by the presence of lateral loads that would have little effect on the column strength of stiffer members. For this reason, columns with slenderness ratios greater than 120 should not be used unless special care is taken to insure that the effects of

TABLE 6a.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6063-T6 BRIDGE STRUCTURES WELDED)

Type of Stress	Specification No.	Type of Member or Component	Allowable Stress, ksi
TENSION, axial, net section	I-1a	Any tension member	6
TENSION in extreme fibers of beams, net section	I-2a	Structural shapes, rectangular tubes, built-up members bent about X-axis 	6
	I-3a	Round or oval tubes	6.5
	I-4a	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis 	6.5
BEARING	I-5a	On rivets and bolts	9(b)
	I-6a	On milled surfaces and pins	6

				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs I-8a to I-10a)	I-7a	Columns (a)	6	- - - -	6	L/r = 87	$\frac{45,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7a)	I-8a	Outstanding flanges and legs	6	b/t = 4.1	$\frac{12.1}{\sqrt{b/t}}$	b/t = 27	$\frac{1,720}{(b/t)^2}$
		I-9a	Flat plates with both edges supported	6	- - - -	6	b/t = 53	$\frac{17,000}{(b/t)^2}$
		I-10a	Curved plates supported on both edges and walls of round or oval tubes	6	R/t = 10	$\frac{10.7}{(R/t)^{1/4}}$	R/t = 125	- - - -

COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION[a] in extreme fibers of beams, gross section (Also see Specs. I-15a to I-18a)	I-11a	Single-web structural shapes and built-up sections bent about X-axis[a]		6	- - - -	6	L_b/r_y = 104	$\frac{65,000}{(L_b/r_y)^2}$
		I-12a	Round or oval tubes		6.5	R_b/t = 13	$\frac{12.3}{(R_b/t)^{1/4}}$	R_b/t = 125	- - - -
		I-13a	Solid rectangular beams bent about X-axis		6.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 11	$\frac{21.6}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 55	$\frac{6,800}{(d/t)^2 L_b/d}$
		I-14a	Rectangular tubes and box sections[a]		6	- - - -	6	$\frac{L_b S_c}{I_y}$ = 2920	$\frac{17,700}{L_b S_c/I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11a to I-14a)	I-15a	Flat plates with one edge free and one edge supported		6	b/t = 4.4	$\frac{12.6}{\sqrt{b/t}}$	b/t = 32	$\frac{2,240}{(b/t)^2}$
		I-16a	Flat plates with both edges supported		6	- - - -	6	b/t = 53	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11a to I-14a)	I-17a	Flat plates with compression edge free and tension edge supported, bent about X-axis		6.5	b/t = 7.2	$\frac{17.4}{\sqrt{b/t}}$	b/t = 35	$\frac{3,700}{(b/t)^2}$
		I-18a	Flat plates with both edges supported, bent about X-axis		6	- - - -	6	h/t = 185	$\frac{205,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-19a	Unstiffened flat webs		3.5	- - - -	3.5	h/t = 91	$\frac{29,000}{(h/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification 1-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

any lateral loads to which the member may be subjected, such as wind, dead load, or the weight of workmen and equipment, are taken into account by using the provision for combined compression and bending in Specification B-7.

B-3: Compression Splices.—Members designed for compression, if faced for bearing, shall be spliced on four sides sufficiently to hold the abutting parts true to place. The splice shall be as near a panel point as practicable and shall be designed to transmit at least one half of the stress through the splice material. Members not faced for bearing shall be fully spliced for the computed stress. In either case, adequate provision shall be made for transmitting shear.

B-4: Stay Plates.—On the open sides of compression members without webs, the flanges shall be connected by lacing bars, with stay plates as near each end as practicable, or by perforated cover plates. There shall be stay plates at intermediate points where the lacing is interrupted. The length of the end stay plates shall not be less than one and one-fourth times the distance between the nearest lines of connecting rivets, bolts, or welds. The

TABLE 7a.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS (BRIDGE STRUCTURES OF 6063-T6)

Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-20a	5356 5556	6[c]	6[c]
I-21a	4043	4.5	6[c]

[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

thickness of stay plates shall not be less than one-fortieth of the distance between lines of connections.

B-5: Diagonal Lacing.—The slenderness ratio of the part of the flange between the lacing bar connections shall not be more than three-fourths of the slenderness ratio of the member.

B-6: Perforated Cover Plates.—Perforated cover plates may be used instead of tie plates and lacing, provided that: The ratio of length (in direction of stress) to width of hole shall not exceed 2; the clear distance between holes shall not be less than the distance between nearest lines of connecting rivets, bolts or welds; the periphery of the holes at all points shall have a minimum radius of 1 1/2 in.; the thickness of the cover plate shall not be less than one-fortieth of the distance between the nearest lines of connecting rivets, bolts, or welds; and the stress on the net section of the column (omitting the area of the holes in the cover plate) shall not exceed the values given in Specification A-8 or I-8, where t is the thickness of the perforated cover plate and

b is the distance from the edge of the hole to the nearest line of connecting rivets, bolts, or welds.

B-7: Combined Compression and Bending.—A member that carries bending moment in addition to uniform compression (as, for example, an eccentrically loaded column) shall be proportioned in accordance with the following formulas:

For members subjected to combined end load and bending, where the bending moment at the center of the span is equal to or greater than 0.9 of the maximum bending moment in the span,

$$\frac{f_a}{F_a} + \frac{f_b}{F_b\left(1 - \frac{f_a}{F_e}\right)} \leq 1 \quad \ldots\ldots\ldots\ldots \quad (1)$$

in which f_a denotes the average compressive stress on cross section of member produced by axial compressive load, ksi; f_b is the maximum bending stress (compression) caused by transverse loads or end moments in the absence of axial load, ksi; F_a refers to the allowable compressive stress for member considered as an axially loaded column, ksi; and F_b describes the allowable compressive stress for member considered as a beam, ksi.

For bridges and similar structures,

$$F_e = \frac{45{,}000}{\left(\frac{L}{r}\right)^2}$$

For buildings and similar structures,

$$F_e = \frac{51{,}000}{\left(\frac{L}{r}\right)^2}$$

in which L/r denotes the slenderness ratio for a member considered as a column tending to fail in the plane of the applied bending forces.

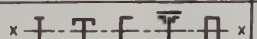
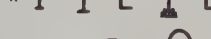
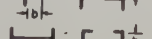
For members subjected to combined end load and bending where the bending moment at the center of the span is not more than one-half the maximum bending moment in the span,

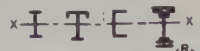
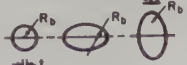
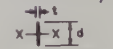
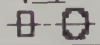
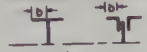
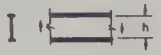
$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

For members subjected to combined end load and bending where the moment at the center of the span is between 0.5 and 0.9 of the maximum moment,

$$\frac{f_a}{F_a} + \frac{f_b}{F_b\left[1 - \left(\frac{2M_c}{M_m} - 1\right)\frac{f_a}{F_e}\right]} \leq 1 \quad \ldots\ldots\ldots \quad (3)$$

TABLE 4b.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES OR IN WELDED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6063-T5 BRIDGE STRUCTURES NONWELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1b	Any tension member	8.5				
TENSION in extreme fibers of beams, net section		A-2b	Structural shapes, rectangular tubes, built-up members bent about X-axis 	8.5				
		A-3b	Round or oval tubes 	9.5				
		A-4b	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	11.5				
BEARING		A-5b	On rivets and bolts	13.5[a]				
		A-6b	On milled surfaces and pins	9				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2, ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs. A-8b to A-10b)	A-7b	Columns	7.5	L/r = 14	8.0 - 0.035 L/r	L/r = 100	$\frac{45,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7b)	A-8b	Outstanding flanges and legs	7.5	b/t = 7.2	9.1 - 0.22 b/t	b/t = 19	$\frac{1,720}{(b/t)^2}$
		A-9b	Flat plates with both edges supported 	7.5	b/t = 23	9.1 - 0.070 b/t	b/t = 58	$\frac{17,000}{(b/t)^2}$
		A-10b	Curved plates supported on both edges and walls of round or oval tubes	7.5	R/t = 16	8.2 - 0.177 $\sqrt{R/t}$	R/t = 200	- - - -

COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15b to A-18b	A-11b	Single-web structural shapes and built-up sections bent about X-axis		7.5	L_b/r_y = 17	8.0 - 0.029 L_b/r_y	L_b/r_y = 120	$\frac{65,000}{(L_b/r_y)^2}$
		A-12b	Round or oval tubes		9.5	R_b/t = 18	10.0 - 0.028 R_b/t	R_b/t = 140	- - - -
		A-13b	Solid rectangular beams bent about X-axis		11.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 11	13.8 - 0.21 $\frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 44	$\frac{8,800}{(d/t)^2\ L_b/d}$
		A-14b	Rectangular tubes and box sections		7.5	$\frac{L_bS_c}{I_y}$ = 80	8.0 - 0.056 $\sqrt{\frac{L_bS_c}{I_y}}$	$\frac{L_bS_c}{I_y}$ = 3,940	$\frac{17,700}{L_bS_c/I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs A-11b to A-14b)	A-15b	Flat plates with one edge free and one edge supported		7.5	b/t = 8.3	9.1 - 0.194 b/t	b/t = 21	$\frac{2,240}{(b/t)^2}$
		A-16b	Flat plates with both edges supported		7.5	b/t = 23	9.1 - 0.070 b/t	b/t = 58	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11b to A-14b)	A-17b	Flat plates with compression edge free and tension edge supported, bent about X-axis		11.5	b/t = 7.0	13.8 - 0.33 b/t	b/t = 28	$\frac{3,700}{(b/t)^2}$
		A-18b	Flat plates with both edges supported, bent about X-axis		7.5	- - - -	7.5	h/t = 165	$\frac{205,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-19b	Unstiffened flat webs		5	h/t = 13	5.3 - 0.024 h/t	h/t = 100	$\frac{29,000}{(h/t)^2}$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

in which M_c is the bending moment at center of span resulting from applied bending loads, in.-kips; and M_m denotes maximum bending moment in span resulting from applied bending loads, in.-kips.

B-8: Transverse Shear in Columns.—In designing lacing or shear webs for columns, the maximum shear on the column shall be computed from the formula:

$$V = 0.02\ A\ (F_c)_{max} + V_t \quad \ldots\ldots\ldots\ldots \quad (4)$$

in which V denotes shear on any transverse section of a column, kips; A refers to the gross area of column cross section, in square inches; V_t describes the shear caused by any transverse loads on the column, kips; and $(F_c)_{max}$ is the maximum allowable compressive stress for short columns, ksi (for example, $(F_c)_{max}$ = 12 for 6063-T6 in bridge structures).

TABLE 5b.—ALLOWABLE STRESSES IN RIVETS AND BOLTS (BRIDGE STRUCTURES OF 6063-T5)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear area	Tension on root area
A-20b	6053-T61 rivets, cold driven	7.5	--
A-21b	6061-T43 rivets, driven at temperatures of from 990°F to 1050°F	8	--
A-22b	2024-T4 bolts	14[a]	23

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

Section C: Beam and Girder Design.

C-1: Allowable Compressive Stress in Beams.—The allowable compressive stress in extreme fibers of beams shall be determined from the formulas in Specifications A-11 to A-14.

Beams whose compression flanges involve webs or outstanding legs of such proportions that local buckling may control the design shall be checked by Specifications A-15 to A-17 or by the method outlined in Part IV, Section M.

C-2: Single-Web Beams.—Because of the simplified form of the formulas for allowable stress in single-web beams and girders in Specification A-11, these formulas give very conservative values of allowable stress for certain conditions, namely for values of L_b/r_y exceeding approximately 50, for load distributions such that the bending moment near the center of the beam is appreciably less than the maximum bending moment in the beam or for beams with transverse loads applied to the bottom flange. If the designer wishes to

compute more precise values of allowable stress for single-web beams and girders, he may make use of the formulas in Part IV, Section L.

C-3: Allowable Shear Stresses in Webs.—The allowable shear stress in flat webs shall not exceed the values given in Specification A-19.

Section D: Design of Plates, Legs, and Webs in Compression.

D-1: Single-Angle, Double-Angle, Tee, or Cruciform Struts.—For struts consisting of a single angle, double angle, tee, or cruciform section, the compressive stress on the gross area shall not exceed the value given by Specification A-7 or by Specification A-8, whichever is smaller.

D-2: Flat Plate Elements of Columns.—For compression members other than those consisting of a single angle, double angle, tee, or cruciform section, the allowable compressive stress shall not exceed the value given by Specification A-7 nor shall it exceed the values given by Specifications A-9 or A-10 unless the special analysis described in Part IV, Section M is utilized.

D-3: Flat Plate Elements of Beams.—Allowable compressive stresses in flat plate elements of beams shall not exceed the values given by Specification A-15 or A-16, unless the special analysis described in Part IV, Section M, is used.

D-4: Stiffeners for Flat Plates in Compression.—Outstanding flanges stiffened by lips or bulbs at the free edge shall be considered as supported on both edges if the moment of inertia of the lip or bulb meets the following requirements:

$$I_L = \frac{b^3 t}{80} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5a)$$

in which b is the clear width of flange, in inches; t denotes the thickness of flange, in inches; and I_L is the moment of inertia of lip or bulb about face of flange, in.^{4}.

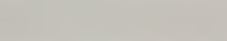
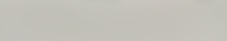
For rectangular lips having the same thickness as the flange, the preceding requirement may be expressed

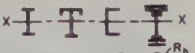
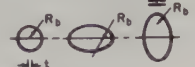
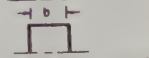
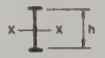
$$b_L = \frac{1}{3} b \quad \ldots\ldots\ldots\ldots\ldots\ldots (5b)$$

in which b_L is the clear width of lip, in inches. Allowable stresses for flanges with lips or bulbs meeting the foregoing requirements shall be determined from Specification A-9 or A-16. The area of the stiffening lips or bulbs is included with the area of the rest of the section in calculating the stresses caused by the loads.

Section E: Plate Girder Design.—Plate girders are not ordinarily fabricated of alloy 6063-T5 or 6063-T6 because this material is not available in the form of sheet and plate. In some cases, however, it may be desirable to use alloy 6063-T5 or 6063-T6 for the flanges of a plate girder and alloy 6061-T6 for the web. In this case, the web and stiffeners should be designed in accordance with the provisions of this committee's "Specifications for Structures of Aluminum Alloys 6061-T6 and 6062-T6." The allowable stresses in the girder flanges would be governed by the provisions of these specifications for beams of 6063-T6 or 6063-T5.

TABLE 6b.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6063-T5 BRIDGE STRUCTURES WELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		I-1b	Any tension member	6				
TENSION in extreme fibers of beams, net section		I-2b	Structural shapes, rectangular tubes, built-up members bent about X-axis	6				
		I-3b	Round or oval tubes	6.5				
		I-4b	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	6.5				
BEARING		I-5b	On rivets and bolts	9(b)				
		I-6b	On milled surfaces and pins	8				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2, ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION,(a) gross section (Also see Specs. I-8b to I-10b)	I-7b	Columns(a)	6	L/r = 57	8.0 - 0.035 L/r	L/r = 100	$\frac{45,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7b)	I-8b	Outstanding flanges and legs 	6	b/t = 4.1	$\frac{12.1}{\sqrt{b/t}}$	b/t = 27	$\frac{1,720}{(b/t)^2}$
		I-9b	Flat plates with both edges supported	6	b/t = 44	9.1 - 0.070 b/t	b/t = 58	$\frac{17,000}{(b/t)^2}$
		I-10b	Curved plates supported on both edges and walls of round or oval tubes 	6	R/t = 10	$\frac{10.7}{(R/t)^{1/4}}$	R/t = 125	- - - -

COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION (a) in extreme fibers of beams, gross section (Also see Specs. I-15b to I-18b)	I-11b	Single-web structural shapes and built-up sections bent about X-axis (a)		6	L_b/r_y = 69	8.0 - 0.029 L_b/r_y	L_b/r_y = 120	$\frac{65,000}{(L_b/r_y)^2}$
		I-12b	Round or oval tubes		6.5	R_b/t = 13	$\frac{12.3}{(R_b/t)^{1/4}}$	R_b/t = 125	- - - -
		I-13b	Solid rectangular beams bent about X-axis		6.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 11	$\frac{21.6}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 55	$\frac{8,800}{(d/t)^2 L_b/d}$
		I-14b	Rectangular tubes and box sections (a)		6	$\frac{L_b S_c}{I_y}$ = 1280	$8.0 - 0.056\sqrt{\frac{L_b S_c}{I_y}}$	$\frac{L_b S_c}{I_y}$ = 3940	$\frac{17,700}{L_b S_c / I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11b to I-14b)	I-15b	Flat plates with one edge free and one edge supported		6	b/t = 4.4	$\frac{12.8}{\sqrt{b/t}}$	b/t = 32	$\frac{2,240}{(b/t)^2}$
		I-16b	Flat plates with both edges supported		6	b/t = 44	9.1 - 0.070 b/t	b/t = 58	$\frac{17,000}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11b to I-14b)	I-17b	Flat plates with compression edge free and tension edge supported, bent about X-axis		6.5	b/t = 7.2	$\frac{17.4}{\sqrt{b/t}}$	b/t = 35	$\frac{3,700}{(b/t)^2}$
		I-18b	Flat plates with both edges supported, bent about X-axis		6	- - - -	6	h/t = 185	$\frac{205,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-19b	Unstiffened flat webs		3.5	h/t = 75	5.3 - 0.024 h/t	h/t = 100	$\frac{29,000}{(h/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification I-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter)

Section F: Riveted and Bolted Connections.

F-1: Allowable Loads.—The allowable loads on rivets and bolts shall be calculated using the allowable shear stresses in Specifications A-22 to A-25 and the allowable bearing stresses in Specification A-5. In the latter specification, the allowable bearing stress depends on the ratio of edge distance to rivet or bolt diameter, where the edge distance is the distance from the center of the rivet or bolt to the edge of a plate or shape toward which the pressure of the rivet or bolt is directed.

F-2: Effective Diameter.—The effective diameter of rivets shall be taken as the hole diameter, but shall not exceed the nominal diameter of the rivet by more than 4% for cold driven rivets or 7% for hot driven rivets. The effective diameter of pins and bolts shall be the nominal diameter of the pin or bolt.

F-3: Shear Area.—The effective area of a rivet or bolt in any shear plane shall be based on the effective diameter, except that for bolts with threads included in the shear plane, the effective shear area shall be based on the root

TABLE 7b.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS
(BRIDGE STRUCTURES OF 6063-T5)

Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-20b	5356 5556	6[c]	6[c]
I-21b	4043	4.5	6[c]

[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

diameter. Shear areas of bolts are listed with recommended hole sizes in Table 8.

F-4: Bearing Area.—The effective bearing area of pins, bolts, and rivets shall be the effective diameter multiplied by the length in bearing, except that for countersunk rivets, half of the depth of the countersink shall be deducted from the length.

F-5: Arrangement and Strength of Connections.—Connections shall be arranged to minimize the eccentricity of loading on the member. Members and connections shall be proportioned to take into account any eccentricity of loading by the connections.

F-6: Net Section.—The net section of a riveted or bolted tension member is the sum of the net sections of its component parts. The net section of a part is the product of the thickness of the part multiplied by its least net width. The net width for a chain of holes extending across the part in any straight or broken line shall be obtained by deducting from the gross width the sum of the

diameters of all the holes in the chain and adding $s^2/4g$ for each gage space in the chain. In the correction quantity $s^2/4g$, s is the spacing parallel to direction of load (pitch) of any two successive holes in the chain, in inches, and g denotes the spacing perpendicular to direction of load (gage) of the same holes, in inches.

The net section of the part is obtained from that chain which gives the least net width. The hole diameter to be deducted shall be the actual hole diameter for drilled or reamed holes and the hole diameter plus 1/16-in. for punched holes.

For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of the angle, less the thickness.

For splice members, the thickness shall be only that part of the thickness of the member that has been developed by rivets or bolts beyond the section considered.

TABLE 8.—RECOMMENDED HOLE SIZES FOR ALUMINUM ALLOY RIVETS

Rivet diameter, in inches	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
Cold Driven Rivets								
Hole diameter, in inches	0.386	0.453	0.516	0.578	0.641	0.766	0.891	1.016
Drill size	W	29/64	33/64	37/64	41/64	49/64	57/64	1-1/64
Single shear area, in square inches	0.1170	0.1612	0.2091	0.2624	0.3227	0.4608	0.6235	0.8107
Hot Driven Rivets								
Hole diameter, in inches	0.397	0.469	0.531	0.594	0.656	0.781	0.922	1.063
Drill size	X	15/32	17/32	19/32	21/32	25/32	59/64	1-1/16
Single shear area, in square inches	0.1238	0.1728	0.2215	0.2771	0.3380	0.4791	0.6677	0.8875

F-7: Effective Sections of Angles.—If an angle in tension is connected on one side of a gusset plate, the effective section shall be the net section of the connected leg plus one half of the section of the outstanding leg unless the outstanding leg is connected by a lug angle. In the latter case, the effective section shall be the entire net section of the angle. The lug angle shall be designed to develop at least one half the total load in the member and shall be connected to the main member by at least two fasteners.

F-8: Grip of Rivets and Bolts.—If the grip of rivets or bolts carrying calculated stress exceeds four and one-half times the diameter, the allowable load per rivet or bolt shall be reduced. The reduced allowable load shall be the normal allowable load divided by (1/2 + G/9D) in which G is the grip, and D the nominal diameter of the rivet or bolt. If the grip of a rivet exceeds six

times the diameter, special care shall be taken in driving to insure that the holes will be filled completely.

F-9: Spacing of Rivets and Bolts in Built-Up Compression Members.—The pitch in the direction of stress shall be such that the allowable stress on the individual outside plates and shapes, treated as columns having a length equal to the rivet or bolt pitch in accordance with Specification A-7, exceeds the calculated stress. The gage at right angles to the direction of stress shall be such that the allowable stress in the outside plates, treated as plates having a width equal to the rivet or bolt gage in accordance with Specification A-9, exceeds the calculated stress.

F-10: Stitch Rivets and Bolts.—Where two or more web plates are in contact, there shall be stitch rivets or bolts to make them act in unison. In compression members, the pitch and gage of such rivets or bolts shall be determined as outlined in Specification F-9. In tension members, the maximum pitch or gage of such rivets shall not exceed a distance, in inches, equal to (3 + 20t) in which t is the thickness of the outside plates, in inches. In tension members composed of two angles in contact, the pitch of the stitch rivets or bolts shall not exceed 10 in. in the case of bridges and similar structures or 20 in. for buildings and similar structures, nor shall such a member have less than two stitch rivets or bolts.

F-11: Minimum Spacing of Rivets.—The distance between centers of rivets shall not be less than three times the diameter of the rivets, and the distance between centers of bolts shall not be less than 2 1/2 times the diameter of the bolts.

F-12: Edge Distance of Rivets or Bolts.—The distance from the center of a rivet or bolt to a sheared, sawed, rolled, or planed edge shall be not less than one and one-half times the diameter, except in flanges of beams and channels, where the minimum distance may be one and one-fourth times the diameter. For rivets or bolts under computed stress, the distance from the center of the rivet or bolt to the edge of the plate or shape toward which the pressure of the rivet or bolt is directed should normally be at least twice the nominal diameter of the rivet or bolt. In cases in which a shorter edge distance must be used, the allowable bearing stress shall be reduced in accordance with Table 4[a].

The distance from the edge of a plate to the nearest rivet or bolt line shall not exceed six times the thickness of the plate.

F-13: Extra Rivets or Bolts.—If rivets or bolts carrying calculated stress pass through fillers more than 1/4 in. thick, the fillers shall be extended beyond the connected member and the extension secured by enough additional rivets or bolts to distribute the total stress in the member uniformly over the combined section of the member and filler.

Section G: Miscellaneous Design Rules.

G-1: Reversal of Load.—Members in structures subject to reversal of load under one passage of live load shall be proportioned as follows: Determine the tensile load and the compressive load and increase each by 50% of the smaller; then proportion the member and its connections so that the allowable stresses given in Sections A through F will not be exceeded by either increased load.

G-2: Slenderness Ratio of Tension Members.—Tension members with values of slenderness ratio L/r greater than 150 shall not be used unless special care is taken to insure that such members are designed to resist any lateral loads such as wind, dead load, or the weight or workmen and equipment.

Stresses caused by the combined bending and tensile loadings shall not exceed allowable limits.

G-3: Stay Plates for Tension Members.—Segments of tension members not directly connected to each other shall be stayed together. The length of the stay plate shall be not less than three-fourths of the distance between the nearest lines of connecting rivets, bolts, or welds. Stay plates that are fastened by rivets or bolts shall be fastened to each segment of the tension member by at least two rivets or bolts. The distance between stay plates shall be such that the slenderness ratio of the individual segments of the member between stay plates does not exceed the slenderness ratio of the member as a whole.

Section H: Fabrication.

H-1: Laying Out.

a. Hole centers may be center punched and cutoff lines may be punched or scribed. Center punching and scribing shall not be used where such marks would remain on fabricated material.

b. A temperature correction shall be applied where necessary in the layout of critical dimensions. The coefficient of expansion shall be taken as 0.000012 per degree Fahrenheit.

H-2: Cutting.

a. Material may be sheared, sawed, cut with a router or arc cut. All edges which have been cut by the arc process shall be planed to a depth of 1/4 in. to remove edge cracks.

b. Cut edges shall be true and smooth, and free from excessive burrs or ragged breaks.

c. In bridge structures, sheared edges of plates carrying calculated stresses shall be planed to a depth of 1/4 in.

d. Re-entrant cuts shall be avoided wherever possible. If used, they shall be filleted by drilling prior to cutting.

e. Oxygen cutting of aluminum alloys is not permitted.

H-3: Heating.—Structural material shall not be heated, with the following exceptions:

a. Material may be heated to a temperature not exceeding 400°F for a period not exceeding 30 min in order to facilitate bending. Such heating shall be done only when proper temperature controls and supervision are provided to insure that the limitations on temperature and time are carefully observed.

b. Hot-driven rivets shall be heated as specified in Section H-5.

H-4: Punching, Drilling, and Reaming.—Rules for punching, drilling, and reaming are as follows:

a. In bridge structures, rivet or bolt holes in main members shall be subpunched or subdrilled and reamed to finished size after the parts are firmly bolted together or shall be drilled to finished size after the parts are firmly bolted together. The amount by which the diameter of a subpunched hole is less than that of the finished hole shall be at least 1/4 the thickness of the piece and in no case less than 1/32 in. If the metal thickness is greater than the diameter of the hole, punching shall not be used.

b. Rivet or bolt holes in secondary material not carrying calculated stress may be punched or drilled to finish size before assembly.

c. The finished diameter of holes for cold-driven rivets shall be not more than 4% greater than the nominal diameter of the rivet. Recommended hole sizes are listed in Table 8.

d. The finished diameter of holes for hot-driven rivets shall be not more than 7% greater than the nominal diameter of the rivet. Recommended hole sizes are listed in Table 8.

e. The finished diameter of holes for bolts shall be not more than 1/16 in. larger than the nominal bolt diameter.

f. If any holes must be enlarged to admit the rivets or bolts, they shall be reamed. Poor matching of holes shall be cause for rejection. Holes shall not be drifted in such a manner as to distort the metal. All chips lodged between contacting surfaces shall be removed before assembly.

H-5: Riveting.

a. The driven head of aluminum alloy rivets preferably shall be of the flat or the cone-point type, with dimensions as follows:

1. Flat heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height not less than 0.4 times the nominal rivet diameter.

2. Cone-point heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height to the apex of the cone not less than 0.65 times the nominal rivet diameter. The included angle at the apex of the cone shall be approximately 127°.

b. Rivets shall be driven hot or cold as called for on the plans, provision for heating being as follows:

1. Hot-driven rivets shall be heated in a hot-air type furnace providing uniform temperatures throughout the rivet chamber and equipped with automatic temperature controls.

2. Hot-driven rivets shall be held at from 990°F to 1050°F for not less than 15 min and for not more than 1 hr before driving.

3. Hot rivets shall be transferred from the furnace to the work and driven with a minimum loss of time.

c. Rivets shall fill the holes completely. Rivet heads shall be concentric with the rivet holes and shall be in proper contact with the surface of the metal.

d. Defective rivets shall be removed by drilling.

H-6: Painting.—Structures of the alloy covered by these specifications are not ordinarily painted except where (1) the aluminum alloy parts are in contact with, or are fastened to, steel members or other dissimilar materials, or (2) the structures are to be exposed to extremely corrosive conditions. Painting procedure is covered in the following paragraphs, and methods of cleaning and preparation are found in Specification H-7. (Treatment and painting of the structure in accordance with United States Military Specification MIL-T-704 is also acceptable.)

a. Where the aluminum alloy parts are in contact with or are fastened to, steel members or other dissimilar materials, the aluminum shall be kept from direct contact with the steel or other dissimilar material by painting as will be described:

1. Aluminum surfaces to be placed in contact with steel shall be given one coat of zinc chromate primer in accordance with United States Military Specification MIL-P-735 or the equivalent or one coat of a suitable nonhardening joint compound capable of excluding moisture from the joint during prolonged service. Additional protection can be provided by applying the joint compound in addition to the zinc chromate primer. Zinc chromate paint shall be allowed to dry hard before assembly of the parts. The steel surfaces to be placed in contact with aluminum shall be painted with good quality priming paint, such as red lead conforming to Federal Specification TT-P-86 or zinc chromate primer in accordance with United States Military Specification MIL-P-735, followed by one coat of paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962-49, Type II, Class B) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or the equivalent. Stainless steel or aluminized, hot-dip galvanized or electro-galvanized steel placed in contact with aluminum need not be painted.

2. Aluminum surfaces to be placed in contact with wood, concrete, or masonry construction, except where the aluminum is to be embedded in concrete, shall be given a heavy coat of an alkali-resistant bituminous paint before installation. The bituminous paint used shall meet the requirements of United States Military Specification MIL-P-6883. The paint shall be applied as it is received from the manufacturer without the addition of any thinner.

3. Aluminum surfaces to be embedded in concrete ordinarily need not be painted, unless corrosive components are added to the concrete or unless the concrete is subjected for extended periods to extremely corrosive conditions. In such cases aluminum surfaces should be given one coat of suitable quality paint such as zinc chromate primer conforming to United States Military Specification MIL-P-735 or equivalent, or should be wrapped with a suitable plastic tape applied in such a manner or to provide adequate protection at the overlap.

4. Water that comes in contact with aluminum after first running over a heavy metal such as copper may contain trace quantities of the dissimilar metal or its corrosion product, which will cause corrosion of the aluminum. Protection can be obtained by painting or plastic coating the dissimilar metal or by designing the structure so that the drainage from the dissimilar metal is diverted away from the aluminum.

5. Bolts and other fasteners used with aluminum shall be of aluminum, stainless steel, or aluminized, hot-dip galvanized or electro-galvanized steel.

b. Although structures of the alloy covered by these specifications are not ordinarily painted, there may be applications where the structures are to be exposed to extremely corrosive conditions which make over-all painting advisable. In such instances, all contacting metal surfaces shall be painted before assembly with one coat of zinc chromate primer in accordance with United States Military Specification MIL-P-735 or the equivalent. The primer shall be allowed to dry hard before assembly of the parts. All other surfaces shall be given one shop coat of zinc chromate primer made in accordance with United States Military Specification MIL-P-735 or the equivalent and then shall be given a second shop coat of paint consisting of 2 1/4 lb of nonleafing aluminum paste pigment (Alcoa No. 221, Reynolds 10 LN, or equivalent) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or the equivalent. The nonleafing paint shall be used to permit detection of an incomplete application of the subsequent paint coat. After erection, bare spots shall

be touched-up with zinc chromate primer followed by a touch-up coat of non-leafing aluminum paint as specified previously. The completed structure shall be finished according to one of the following methods:

1. One field coat of leafing aluminum paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962-49, Type II, Class B) per gallon of varnish meeting Federal Specification TT-V-81, Type II, or equivalent.
2. One or more field coats of alkyd base enamel pigmented to meet a desired color scheme.
3. Where specific chemicals especially corrosive to aluminum are encountered (such as strong caustic or strong mineral acids) paint systems that provide superior protection against the specific chemicals involved may be used.

H-7: Cleaning and Treatment of Metal Surfaces.—All surfaces to be painted shall be cleaned as follows:

a. Surfaces of metal shall be cleaned immediately before painting by a method that will remove all dirt, oil, grease, chips, and other foreign substances.

b. Either of the two following methods of cleaning may be used on exposed metal surfaces:

1. Chemical Cleaning: Parts may be immersed in, or swabbed with, a solution of phosphoric acid and organic solvents meeting United States Military Specification MIL-M-10578, after diluting one volume of the concentrate with three volumes of water. The solution temperature shall be between 50°F and 90°F. The solution shall remain in contact with the metal not less than 5 min and shall not be allowed to dry on the surface. Residual solution shall be thoroughly removed by flushing with clear water.

The preceding treatment will provide adequate paint adhesion under most conditions; however, if unusual conditions of exposure such as continuous high humidity or highly corrosive atmospheres are anticipated, better paint adhesion will be obtained by following the treatment with application of a commercial chromate conversion solution such as those listed on Military Qualified Products list QPL-5541-16. Such solution shall be applied in accordance with the supplier's instructions.

If it is desirable to apply these treatments in the factory, the stages preceding the conversion chromate application may be modified in accordance with commercial practices for applying chromate conversion coatings.

If treatment is applied at the factory, a shop primer should be applied because handling subsequent to treatment will contaminate the treated surface. If desirable, complete finishing may be performed at the factory following factory pretreatment.

2. Sandblasting: Standard mild sandblasting methods may be used on sections more than 1/8 in. thick.

c. For contacting surfaces only, the metal may be cleaned in accordance with Specification H-7b, or with a solvent such as mineral spirits or benzine.

d. Flame cleaning is not permitted.

PART III. SPECIFICATIONS FOR WELDED STRUCTURES

Section I: Allowable Stresses for Welded Parts.—Welded members are proportioned in accordance with the general rules of Part II, except that it is necessary to lower the allowable stresses in a "reduced strength zone" extending for a distance of 1 in. on either side of a weld. The 1-in. distance is irrespective of thickness and is measured from the centerline of a butt weld or the heel of a fillet weld.

The allowable stresses for welded cross sections whose entire area lies within 1 in. of a weld are given by Specifications I-1 and I-21 in Tables 6a to 6d. Allowable shear stresses in fillet welds are given by Specifications I-22 to I-24 in Tables 7a to 7d.

I-25: Cross Sections with Part of Area Affected by Heat of Welding.—If less than 15% of the area of a given cross section lies within 1 in. of a weld, the effect of the welds can be neglected and allowable stress for that cross section can be calculated by the formulas in Table 4. If the area of a cross section that lies within 1 in. of a weld is between 15% and 100% of the total area of the cross section, the allowable stress shall be calculated by the formula

$$f_{pw} = f_n - \frac{A_w}{A}\left(f_n - f_w\right) \quad \ldots\ldots\ldots\ldots (10)$$

in which f_{pw} denotes the allowable stress on cross section, part of whose area lies within 1 in. of a weld, ksi; f_n is the allowable stress for same cross section if there were no welds present (see Table 4), ksi; f_w refers to the allowable stress for same cross section if entire area lies within 1 in. of a weld (see Table 6), ksi; A is the net area of cross section of a tension member or tension flange of a beam, or gross area of cross section of a compression member or compression flange of a beam, in square inches. (A beam flange is considered to consist of that portion of the member farther than 2c/3 from the neutral axis, where c is the distance from the neutral axis to the extreme fiber.); and A_w describes the area within area A that lies within 1 in. of weld, in square inches.

I-26: Columns and Single-Web Beams with Welds at Locations Other Than Ends and Cantilever Columns and Single-Web Beams.—The allowable stresses in Specifications I-7 and I-8 apply to members supported at both ends with welds at the ends only (not farther from the supports than 0.05 of the length of the column or beam). For cantilever columns or beams and for columns and beams having welds at locations other than the ends, the allowable stress shall be determined from the following:

a. Members with welds affecting the entire cross section:

Alloy 6063-T6:

Bridges and Similar Structures		Buildings and Similar Structures		
$f_n > 11.8$	$f_w = 6$	$f_n > 13.3$	$f_w = 6.5$	(11a)
$11.8 \geq f_n > 1.7$	$f_w = \frac{5.6}{\sqrt{12.7-f_n}}$	$13.3 \geq f_n > 1.9$	$f_w = \frac{6.7}{\sqrt{14.4-f_n}}$	
$f_n \leq 1.7$	$f_w = f_n$	$f_n \leq 1.9$	$f_w = f_n$	

Alloy 6063-T5:

Bridges and Similar Structures		Buildings and Similar Structures		
$f_n > 7.6$	$f_w = 6$	$f_n > 8.5$	$f_w = 6.5$	(11b)
$7.6 \geq f_n > 1.5$	$f_w = \frac{3.9}{\sqrt{8.0-f_n}}$	$8.5 \geq f_n > 1.7$	$f_w = \frac{4.7}{\sqrt{9.0-f_n}}$	
$f_n \leq 1.5$	$f_w = f_n$	$f_n \leq 1.7$	$f_w = f_n$	

b. Members with welds affecting less than the entire cross section: The allowable stress shall be determined from Eq. 10, in which the value of f_w is given by Eqs. 11a or 11b.

Section K: Fabrication.

K-1: General.—These specifications are proposed for application to both field and shop welding operations. The general recommendations and regulations shown in the American Welding Society Specifications D2.0-47 "Welded Highway and Railway Bridges" 1947 and D1.0-46 "Code for Arc and Gas Welding in Building Construction" 1946 apply as well to welded 6063-T5 and 6063-T6 structures. Detail requirements in these specifications apply only to steel structures. Detail requirements for welding alloy 6063-T6 and 6063-T5 are given in the following paragraphs.

K-2: Preparation for Welding.—Dirt, Grease, forming or machining lubricants, or any organic material shall be removed from the areas to be welded by cleaning with a suitable solvent or by vapor degreasing.

Additional operations to remove the oxide coating just prior to welding are required when the inert gas tungsten arc welding method is used. This may be done by etching or by scratch brushing. The oxide coating may not need to be removed if the welding is performed with the automatic or semiautomatic inert gas shielded metal arc.

Suitable edge preparation to assure 100% penetration in butt welds shall be used. Flame cutting shall not be used. Sawing, chipping, machining, shearing, or arc cutting may be used.

K-3: Welding Procedure.—Parts shall be welded with an arc or resistance welding process. No welding process that requires the use of a welding flux shall be used. The filler metal shall be aluminum alloy 5556, 5356, or 4043. Other filler metal alloys may be used provided that they are capable of meeting the qualification test requirements and result in welds having resistance to corrosion equal to or greater than welds made with filler alloys 5556, 5356, and 4043. Preheating for welding is permissible provided the temperature does not exceed 400°F for a total time of 30 min.

K-4: Qualification of Welding Procedure and Welding Operator.—The welding process and welding operators shall both meet a qualification test. The method of qualification shall be mutually established by the inspecting agency and the contractor or shall conform to the method described in the ASME Boiler and Pressure Vessel Code, Section IX, "Welding Qualifications," Part B, 1962. Aluminum alloy 6063-T5 or 6063-T6 shall be used for the qualification test plates.

The minimum required tensile strength of reduced section specimens in the procedure qualification test is 17 ksi. In addition to the tensile test, side-bend or face-bend and root-bend tests (either longitudinal or transverse) are required. Operators are qualified on the basis of bend tests and a fillet weld soundness test.

K-5: Rewelding Defects.—Portions of joints that have been rejected on inspection because of defects may be repaired only by rewelding. The defective area shall be removed by chipping or machining. Flame cutting shall not be used. Before rewelding, the joint shall be inspected to insure that all of the defective weld has been removed and that the joint is accessible so that the welding operator can obtain full penetration through the joint.

PART IV. SPECIAL PROVISIONS

Section L.—Single-Web Beams and Girders.—If the designer wishes to compute more precise values of allowable compressive stress for single-web beams and girders, the value of r_y in Specification A-11 may be replaced by an "effective r_y" given by one of the following formulas:

For beam spans subjected to end moment only or to transverse loads applied at the neutral axis of the beam,

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y\, d}{S_c}}\sqrt{1 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2} \qquad \ldots\ldots\ldots (12)$$

For beams subjected to transverse loads applied on the top flange (where the load is free to move laterally with the beam if the beam should buckle),

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y\, d}{S_c}\left[-0.5 + \sqrt{1.25 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right]} \quad \ldots\ (13)$$

For beams subjected to transverse loads applied on the bottom flange (where the load is free to move laterally with the beam if the beam should buckle),

$$\text{Effective } r_y = \frac{C}{1.7}\sqrt{\frac{I_y\, d}{S_c}\left[0.5 + \sqrt{1.25 + 0.152\,\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right]} \quad \ldots\ (14)$$

in which C is the coefficient depending on type of loading, as given in Table 9; d denotes the depth of beam, in inches; I_y refers to the moment of inertia

TABLE 9.—VALUES OF COEFFICIENT C IN FORMULAS FOR ALLOWABLE STRESS IN SINGLE-WEB BEAMS AND GIRDERS

Description of Loading	Value of Coefficient, C
Beams restrained against lateral displacement at both ends of span	
Uniform bending moment, uniform transverse load, or two equal concentrated loads equidistant from the center of the span	1.00
Bending moment varying uniformly from a value of M at one end to β M at the other end	
β = 0.5	1.14
β = 0	1.33
β = -0.5	1.53
β = -1.0	1.60
Concentrated load at center of span	1.16
Cantilever beams	
Concentrated load at end of span	1.13
Uniform transverse load	1.43

of beam about axis parallel to web, in.^{4}; J describes the torsion constant of beam, in.^{4} (Values of J are published for many standard shapes (6). Values of J for plates and shapes not published may be calculated by assuming the section to be composed of rectangles and taking the sum of the terms $bt^3/3$ for each rectangle, in which b equals the length and t the thickness of the rec-

tangle, both in inches. The value of J for a built-up member is the sum of the individual values of J for the sections of which it is composed.); and S_c is the section modulus of beam for compression flange, in cubic inches. For a beam that is unsymmetrical about the horizontal axis, I_y, S_c, and J are calculated as though the beam were symmetrical with both flanges the same as the compression flange of the actual beam.

Section M: Effective Width of Thin Plates in Compression.—Allowable compressive stresses in flat plate elements of columns or beams other than single angles, double angles, tees or cruciform sections may be permitted to exceed the values given by Specification A-8, A-9, A-15, or A-16, provided that the following steps are taken to insure a suitable margin of safety against the weakening effects of local bucking of plates, legs, and webs:

M-1: Columns.

a. Compute the compressive stress f_c on the flat plate, leg, or web in question, based on the design loads and the gross area, without regard to local buckling. This stress must be within allowable limits as defined in Specification A-7.

b. Compute the allowable compressive stress, f_1, for the flat plate, leg, or web from Specification A-8 or A-9. If the actual stress, f_c, does not exceed this limiting value, local buckling is not a problem and the full gross area of the plate, leg, or web may be considered effective.

c. If the actual compressive stress exceeds the allowable value found in step b, only a part of the unsupported width of the flat plate, leg, or web shall be included in computing its effective area. The part of the unsupported width of any individual flat plate, leg or web which may be considered effective shall be found from

$$b_e = b \frac{f_1}{f_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

in which b_e refers to that part of the unsupported width considered effective, in inches; b denotes the unsupported width, in inches; f_c is the compressive stress based on gross area from step a, ksi; and f_1 describes the allowable stress found in step b, ksi.

d. Compute the compressive stress on the effective area. This is simply the axial load divided by the total effective area, which, in turn, is simply the sum of the effective areas of the component parts.

e. The compressive stress on the effective area computed in accordance with step d shall not exceed allowable limits as defined in Specification A-7 for the gross area.

f. Steps c, d, and e provide a suitable factor of safety against collapse of the member as a whole, but do not necessarily provide complete protection against local buckling of individual flat surfaces at the design load. Where local buckling at the design load cannot be tolerated because of appearance, or for other reasons, the computed compressive stress on the gross area, f_c, shall not exceed 1.6 f_1, where f_1 is the compressive stress given in Specification A-8 or A-9 for the b/t ratio in question. Regardless of whether or not this limitation is placed on f_c, the member must still be checked by the method outlined in steps a through e to insure an adequate factor of safety against collapse.

M-2: Beams.—The procedure in Section M-1 can also be applied to beams. In the case of a beam or girder, the stress f_1 shall be determined from Specification A-15 or A-16 and the compressive stress on the effective area shall be determined as follows: Compute the compressive extreme fiber stress f_c for the gross section of the beam or girder and then multiply this value by the ratio of the gross compression flange area to the effective compression flange area, including in each flange area not only the flange proper, but also one-sixth of the area of the web. The stress on the effective area shall not exceed allowable limits as defined in Specifications A-11 to A-14.

PART V. EXPLANATION OF SPECIFICATIONS

Section A: Summary of Allowable Stresses.—The allowable stresses for bridges and similar structures in these specifications represent a factor of safety of at least 1.85 on minimum yield strength and 2.2 on minimum ultimate strength. These factors of safety are reduced somewhat from those used in the earlier specifications prepared by this committee (1),(2), on the basis of the increased service experience and more extensive test data now available for aluminum alloy structures. The factor of safety of 1.85 on yielding is the same as the factor of safety based on the mill coupon yield strength value used in the AASHO and AREA specifications for steel bridges (3,4). The factor of safety of 2.2 on ultimate strength is conservative in comparison with the factor of safety on collapse strength of columns and beams incorporated in the AASHO and AREA specifications for steel bridges, on the basis of the analysis of column strength made in the Column Research Council "Guide to Design Criteria for Metal Compression Members," (9) the results of tests on steel beams reported by R. A. Hechtman, F. ASCE, J. S. Hattrup, M. ASCE, E. F. Styer, and J. L. Tiedemann (10), and the mechanical properties of mild steel structural shapes as reported by L. S. Beedle, F. ASCE, and Lambert Tall, A. M. ASCE (11).

The allowable stresses for buildings and similar structures are based on factors of safety of at least 1.65 on minimum yield strength and 1.95 on minimum ultimate strength. These factors of safety are similar to those used in the AISC specifications for steel buildings (5),(9),(10),(11). In the following paragraphs, the factors of safety used to obtain allowable stresses for buildings and similar structures are listed in parentheses.

A-3: Tension in Extreme Fibers of Round or Oval Tubular Beams.—The allowable tensile stress for round or oval tubes subjected to bending is somewhat higher than for structural shapes because analysis and tests have demonstrated that yielding or failure of tubular beams does not take place until the bending moment considerably exceeds the value that would be predicted on the basis of the ordinary flexure formula (12),(13).

A-4: Tension in Extreme Fibers of Rectangular Bars and Plates and Single-Web Shapes Bent About Y-Axis.—As in the case of round tubes, theory and tests have shown that aluminum alloy members of these shapes can undergo bending moments that are considerably higher than those predicted on the basis of the ordinary flexure formula (13),(14),(15).

A-5: Bearing on Rivets and Bolts.—Allowable bearing stresses were determined by applying a factor of safety of 1.85 (or 1.65) to minimum bearing yield strength and 2.2 (or 1.95) to minimum ultimate bearing strength.

A-6: Bearing on Milled Surfaces and Pins.—This allowable stress is equal to two-thirds of the allowable bearing stress on rivets and bolts.

A-7: Compression in Columns.—The formulas in Specification A-7 approximate the tangent modulus column curves with a factor of safety of 2.2 (or 1.95) and with a cutoff at the basic allowable compressive design stress. The tangent modulus column formula is

$$f_C = \frac{\pi^2 E_t}{\left(\frac{k L}{r}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

in which f_C denotes the column strength, ksi; E_t is the tangent modulus corresponding to stress f_C, ksi; L refers to the length of column, in inches; r describes the least radius of gyration of column, in inches; and k is the factor describing the conditions of restraint at the ends of the column.

In the elastic stress range, Eq. 16 is the same as the Euler column formula. In the plastic stress range, Eq. 16 can be approximated by a straight line for aluminum alloys. The applicability of the Euler column formula and the straight line approximation to the tangent modulus curve has been extensively confirmed by tests (16).

The value of the end restraint factor k was considered to be 1.0 for all columns except cantilever columns, for which the value of k was taken to be 2.0. Studies of the effective length of columns in structures have indicated that a k value of 1.0 is conservative for most structural members (17),(18).

A-8 and A-9: Flat Plate Components of Columns.—Allowable stresses for flat plate components of columns and beams were determined by applying a factor of safety of 2.2 (or 1.95) to the strength of plates as given by the formula (20)

$$f_C = \frac{\pi^2 \eta E}{\left(\frac{k' b}{t}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

in which f_C is the buckling strength, ksi; E denotes the modulus of elasticity, ksi; η refers to the modulus reduction factor for buckling of plates in the inelastic stress range; b is the clear width of plate, in inches; t refers to the thickness of plate, in inches; and k' denotes a factor depending on the conditions of support at the edges of the plate. It was assumed that the supported edges of plate elements in unwelded columns are simply supported, so that $k' = 5.13$ for outstanding flanges and 1.63 for plates supported on both edges.

In the inelastic stress range, the factor η was considered to be given by the formula (20):

$$\eta = \frac{E_s}{E}\left(0.330 + 0.670\sqrt{\frac{1}{4} + \frac{3}{4}\frac{E_t}{E_s}}\right) \quad \ldots\ldots\ldots (18)$$

in which E_s is the secant modulus, ksi. The curve given by the foregoing formula is approximated by the formulas in Specification A-8.

A-10: Curved Plates and Tubes in Compression.—Allowable compressive stresses in curved plates and tubes are based on the results of tests of round tubes as analyzed by George Gerard and Herbert Becker (21).

A-11: Single-Web Beams.—The allowable compressive stresses in single-web structural shapes and built-up sections bent about the X-axis are based on the application of a factor of safety of 2.2 (or 1.95) to the lateral, torsional buckling strength of beams. The lateral buckling strength of aluminum alloy beams has been investigated experimentally and analytically for a number of different cross sections (19). Allowable stresses in the inelastic stress range for beams are based on the straight line approximation to the tangent modulus buckling curve that is also used for columns. In deriving the allowable stresses for beams, it was assumed that the beam is held in an upright position at the supported ends but the strengthening effect of any restraint against rotation of the flanges at the supports was neglected.

A-12: Round or Oval Tubes in Bending.—Allowable compressive stresses in extreme fibers of round or oval tubes subjected to bending are determined from calculated buckling strengths based on the mechanical properties of the material and the results of bending tests on tubes of various aluminum alloys (7), (8), (12).

A-13: Solid Rectangular Beams.—The formulas for allowable stresses in rectangular beams are based on the lateral, torsional buckling strength of such beams (14).

A-14: Box Beams.—The formulas for allowable stresses in box beams are based on the lateral, torsional buckling strength of such beams (9a). In deriving these formulas, use was made of the fact that lateral buckling will govern the design only for relatively deep, narrow box beams, and for these members the torsion constant J is roughly proportional to I_y.

A-15 and A-16: Flat Plate Components of Beams.—Outstanding flanges of beams were considered to be partially restrained against rotation at the supported edges ($k' = 4.5$ in Eq. 17) and flat plate compressive elements supported on both edges were considered to be simply supported ($k' = 1.63$ in Eq. 17), based on analysis of the elastic buckling behavior of members with typical proportions, using methods reported by K. Sutter (22).

A-17: Flat Plates with Compression Edge Free and Tension Edge Supported.—The elastic buckling strength of flat plates in bending with the compression edge free and the tension edge supported was determined from Eq. 17 with $k' = 3.5$. The analysis was extended into the plastic stress range on the basis of the treatment of rectangular beams (Specification A-13), because calculations and tests (29) have shown that the apparent stresses (Mc/I) at which the yield strength is reached in the outer fiber of sections such as tees and angles are even higher than for rectangular beams.

A-18: Flat Plates in Bending with Both Edges Supported.—The allowable compressive stresses for flat plates with both edges supported were computed on the basis of the formula for the buckling stress with the edges halfway between the fixed and simply supported conditions (23). The corresponding value of k' in Eq. 17 is 0.60. A factor of safety of 1.35 (or 1.2) was applied to the buckling strength in this case, because tests have demonstrated that the stresses in plates of this type can appreciably exceed the calculated buckling stress without affecting the behavior of the beam (23), (24).

A-19: Shear in Flat Webs.—Allowable shear stresses in flat webs were obtained by applying a factor of safety of 2.2 (or 1.95) to the calculated buck-

ling strength for a web with partial restraint against rotation at the attachment to the flanges (25), giving a value of k in Eq. 17 of 1.25. In the plastic stress range, the plastic reduction factor was considered to be given by Eq. 18 with the exception that the values of the tangent modulus and secant modulus corresponding to a given shear stress were considered to be the same as the values of the tangent modulus and secant modulus corresponding to a compressive stress equal to $\sqrt{3}$ times the shear stress (25).

A-20 and A-21: Allowable Shear in Rivets.—The minimum shear strength of rivets was considered to be equal to the typical strength divided by 1.15. The factors of safety applied to minimum rivet shear strengths in order to obtain allowable shear stresses were 20% higher than the basic factors of safety applied to minimum strength values elsewhere in these specifications.

A-22: Allowable Shear and Tension in Bolts.—The factors of safety applied to minimum shear strength and minimum tensile strength of 2024-T4 bolts are 20% higher than the basic factors of safety on minimum ultimate strength used elsewhere in these specifications.

Section B: Column Design.

B-7: Combined Compression and Bending.—Eq. 1 is based on an interaction formula that gives good agreement with the results of tests on aluminum members subjected to combined compressive end load and uniform bending moment (26). The formula is applicable to members in which the bending is applied about either the strong or weak axis and to members in which the strength is controlled by either overall or local buckling.

Eq. 1 becomes ultraconservative for members in which the bending moment at the center is appreciably less than the maximum bending moment in the column. For such members, Eq. 2 or Eq. 3 is satisfactory.

B-8: Transverse Shear in Columns.—Eq. 4 for transverse shear in columns is similar to an equation used in the German Specifications (38). This equation agrees well with the more complicated expression, based on the work of E. C. Hartmann, F. ASCE (27), which was used in this committee's earlier specifications.

Section D: Design of Plates, Legs, and Webs in Compression.

D-4: Stiffeners for Flat Plates in Compression.—Eqs. 5a and 5b for required size of stiffening lips or bulbs are based on theoretical and experimental studies reported by M. S. Anderson (35) and by P. S. Bulson (36).

Section F: Riveted and Bolted Connections.

F-10: Stitch Rivets and Bolts.—The requirements for spacing of stitch rivets are based on conventional practices that have been found to give satisfactory results for thin-gage construction as well as for the thicker gages more commonly used in heavy-duty structures.

Section I: Allowable Stresses for Welded Parts.—The allowable stresses for cross sections near welds given in Section I are based on the same principles as are the allowable stresses in Section A, with the exception that some of the allowable stresses for cross sections near welds are reduced to account for the softening effect of the heat of welding. The basic strength values used in obtaining the allowable stresses in Tables 6a to 6d are listed in Table 1. The values of minimum shear strength of fillet welds given in Table 10 were used in conjunction with the shear strength of the parent metal in the heat-affected zone as a basis for the values of allowable shear stress in fillet welds given in Tables 7a to 7d.

In obtaining the allowable tensile stress on welds, the tensile strength value of 17 ksi for material affected by the heat of welding was multiplied by a factor of 0.9, and the resulting stress was divided by a factor of safety of 2.2 (or 1.95). The yield strength was divided by a factor of safety of 1.85 (or 1.65). The factor 0.9 was used to take account of the fact that, for welds that receive only visual inspection, the minimum strength value in Table 1 can probably not be considered to have the same reliability as the minimum mechanical properties of the parent metal, even though the weld strength value is based on ASME weld qualification test requirements (31) and on extensive tests (32). Background information on the provisions of Section I, including the use of Eq. 12, can be found in the literature (33), (34).

Tests and analysis of welded aluminum columns (34) have shown that, for simply supported columns (k = 1.0), welds at the ends have little effect on the buckling strength in the range of slenderness ratios where design is controlled by buckling rather than by yielding. In deriving the allowable stresses in Specifications I-7, I-11, and I-14, therefore, end welds were not considered to affect the buckling strength. Similarly, it was considered that welds will not seriously affect the buckling strength of flat plates supported on both edges, as in the cases by Specifications I-9, I-16, I-18, and I-19. However, the allowable stresses in Specifications I-8, I-10, I-12, I-13, I-15, and I-17 are based on the conservative assumption that the buckling strengths of the members covered by these specifications are controlled by the mechanical properties of the heat-affected material immediately adjacent to the weld.

TABLE 10.—MINIMUM SHEAR STRENGTH OF FILLET WELDS[a]

Filler alloy	Transverse shear in single fillet welds and longitudinal shear	Transverse shear in double fillet welds
5556	19.5	30
5356	17	26
4043	12	16

[a] In ksi.

In obtaining formulas for allowable stress based on local buckling of flat plate elements, the values of k' in Eq. 17 were assumed to be the same as for unwelded plates, except that for buckling in the inelastic stress range in the case of Specifications I-8 and I-15, the values of k' were considered to be halfway between the values used for unwelded plates and the values that would apply to plates with fixed edges. This assumption was made to take into account the restraining effect of the weld bead and the surrounding metal that is not affected by the heat of welding.

Section K: Fabrication.

K-3: Welding Procedure.—The use of alloy 5556 or 5356 as a filler metal produces welds of greater strength and ductility than are generally obtained with alloy 4043. Welds in highly restricted locations may sometimes show cracking when 5556 or 5356 filler metal is used. If this condition cannot be eliminated by adjustments of procedure or fixtures, the cracking tendency can be reduced by using 4043 filler metal. The allowable stresses given in Section I can be safely applied to welds made with any of these alloys.

K-4: Qualification of Welding Procedure and Welding Operator.—The minimum requirement of 17 ksi for tensile strength of a reduced-section specimen used in a welding qualification test is the same as the minimum requirement in the ASME Boiler and Pressure Vessel Code (31).

Section L: Single-Web Beams and Girders.—Eqs. 14a to 14c are derived from the general equation for elastic buckling strength of beams (19) by making the approximation that the effects of lack of symmetry of the cross section about an axis perpendicular to the web can be taken into account by calculating J, I_y, and S_c as though both flanges were the same as the compression flange. This assumption is justified by Figs. 5 to 8 of J. W. Clark, M. ASCE, and H. N. Hill, F. ASCE (19), which show that the lateral buckling stress for an I-section is not greatly affected by changes in the size of the tension flange. It is also assumed that the formula for torsion bending constant for I-sections $\left(C_S = d^2 I_y/4\right)$ applies approximately to all sections (30).

Section M: Effective Width of Thin Plates in Compression.

M-1 and M-2: Effective Width of Thin Plates in Compression.—When a flat plate, leg, or web is built in along one or both edges to other parts of a compression member which offer partial edge restraint, the local buckling of the plate, leg, or web does not precipitate collapse of the member as a whole as it probably would in the case of a single-angle strut. For this reason, it is proper to permit a decreased factor of safety against local buckling in such cases if suitable precautions are taken to avoid collapse. Step c of this specification provides a simple method for accomplishing this result by introducing the well-known "effective width" concept. After a plate, leg, or web buckles, a part of its area is considered to be ineffective in supporting load, whereas a strip along each supported edge is considered still fully effective in working with the supporting material to which it is attached. The formula (Eq. 15) for effective width used in step c is generally more conservative than other accepted methods of computing effective width (28).

The limitation placed on the value of f_c in Step f is intended to provide a small factor of safety against local buckling at the design load.

This report is respectfully submitted by the Task Committee on lightweight Alloys, Committee on Metals, Structural Division:

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APPENDIX I.—BIBLIOGRAPHY ON STRUCTURES OF ALUMINUM ALLOY 6063-T5 AND 6063-T6

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31. "Qualification Standard for Welding Procedures, Welders and Welding Operators," ASME Boiler and Pressure Vessel Code, Section IX, 1962, Par. QN-6, p. 18.
32. "The Strength and Ductility of Welds in Aluminum Alloy Plate," by F. G. Nelson, Jr., and F. M. Howell, The Welding Journal Research Supplement, September, 1952, p. 3.
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35. "Compressive Crippling of Structural Sections," by M. S. Anderson, Technical Note 3553, Natl. Advisory Comm. for Aeronautics, Washington, D.C., 1956.
36. "Local Instability Problems of Light Alloy Struts," by P. S. Bulson, Research Report No. 29, The Aluminium Development Assn., 1955.
37. "Structural Design with Formed Aluminium Sheet," by Cedric Marsh, Light Metals, Vol. 18, 1955, pp. 57-59, 86-88, and 124-217.
38. "German Buckling Specifications," DIN 4114, Vol. I, 1952; English translation by T. V. Galambos and J. Jones, Column Research Council, July, 1957.

APPENDIX II.

Allowable stresses for 6063-T5 and 6063-T6 buildings and other structures to which allowable stresses for buildings are normally applied (Tables 4c, 5c, 6c, 7c, 4d, 5d, 6d, 7d).

TABLE 5c.—ALLOWABLE SHEAR STRESSES IN RIVETS AND BOLTS (BUILDING STRUCTURES OF 6063-T6)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear area	Tension on root area
A-20c	6053-T61 rivets, cold driven	8.5	--
A-21c	6061-T43 rivets, driven at temperatures of from 990°F to 1050°F	9	--
A-22c	2024-T4 bolts	16[a]	26

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

TABLE 7c.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS (BUILDING STRUCTURES OF 6063-T6)

Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-20c	5356 5556	6.5[c]	6.5[c]
I-21c	4043	5	6.5[c]

[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

TABLE 5d.—ALLOWABLE SHEAR STRESSES IN RIVETS AND BOLTS
(BUILDING STRUCTURES OF 6063-T5)

Specification Number	Description of Rivet or Bolt	Allowable Stress, ksi	
		Shear on effective shear area	Tension on root area
A-20d	6053-T61 rivets, cold driven	8.5	--
A-21d	6061-T43 rivets, driven at temperatures of from 990° F to 1050° F	9	--
A-22d	2024-T4 bolts	16[a]	26

[a] This allowable shear stress applies to either turned bolts in reamed holes or unfinished bolts in 1/16-in. oversize holes.

TABLE 7d.—ALLOWABLE SHEAR STRESSES IN FILLET WELDS
(BUILDING STRUCTURES OF 6063-T5)

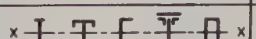
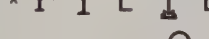
Specification Number	Filler Alloy	Allowable Shear Stress,[a] ksi	
		Transverse shear in single fillet welds or longitudinal shear[b]	Transverse shear in double fillet welds[b]
I-20d	5356 5556	6.5[c]	6.5[c]
I-21d	4043	5	6.5[c]

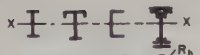
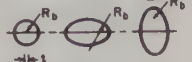
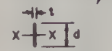
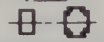
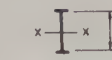
[a] Shear stress is considered to be equal to the load divided by the throat area, regardless of the direction of loading.

[b] Single fillet welds in transverse shear may be treated as double fillet welds in joints so designed as to prevent local bending of the parts adjacent to the fillet weld.

[c] These values are controlled by the shear strength of the parent material; all other values are controlled by the strength of the filler metal.

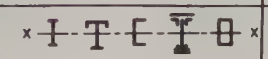
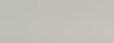
TABLE 4c.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES OR IN WELDED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6063-T6 BUILDING STRUCTURES NONWELDED)

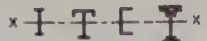
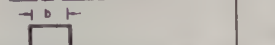
Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1c	Any tension member	15				
TENSION in extreme fibers of beams, net section		A-2c	Structural shapes, rectangular tubes, built-up members bent about X-axis 	15				
		A-3c	Round or oval tubes 	17				
		A-4c	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	19				
BEARING		A-5c	On rivets and bolts	24(a)				
		A-6c	On milled surfaces and pins	16				
				Allowable Stress for Slenderness Less Than S_1 ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs. A-8c to A-10c)	A-7c	Columns	13.5	$L/r = 11$	$14.4 - 0.080\ L/r$	$L/r = 80$	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7c)	A-8c	Outstanding flanges and legs	13.5	$b/t = 8.0$	$16.5 - 0.50\ b/t$	$b/t = 15$	$\frac{1,940}{(b/t)^2}$
		A-9c	Flat plates with both edges supported	13.5	$b/t = 19$	$16.5 - 0.160\ b/t$	$b/t = 46$	$\frac{19,200}{(b/t)^2}$
		A-10c	Curved plates supported on both edges and walls of round or oval tubes	13.5	$R/t = 16$	$15.4 - 0.47\sqrt{R/t}$	$R/t = 140$	- - - -

	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15c to A-18c)	A-11c	Single-web structural shapes and built-up sections bent about X-axis		13.5	L_b/r_y = 14	14.4 - 0.086 L_b/r_y	L_b/r_y = 96	$\frac{74,000}{(L_b/r_y)^2}$
		A-12c	Round or oval tubes		17	R_b/t = 16	18.0 - 0.064 R_b/t	R_b/t = 120	- - - -
		A-13c	Solid rectangular beams bent about X-axis		19	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 12	24.8 - 0.48 $\frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 33	$\frac{9,900}{(d/t)^2 L_b/d}$
		A-14c	Rectangular tubes and box sections		13.5	$\frac{L_b S_c}{I_y}$ = 49	14.4 - 0.128 $\frac{L_b S_c}{I_y}$	$\frac{L_b S_c}{I_y}$ = 2,510	$\frac{20,000}{L_b S_c / I_y}$
COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. A-11c to A-14c)	A-15c	Flat plates with one edge free and one edge supported		13.5	b/t = 6.8	16.5 - 0.44 b/t	b/t = 16	$\frac{2,500}{(b/t)^2}$
		A-16c	Flat plates with both edges supported		13.5	b/t = 19	16.5 - 0.160 b/t	b/t = 46	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11c to A-14c)	A-17c	Flat plates with compression edge free and tension edge supported, bent about X-axis		19	b/t = 7.8	24.8 - 0.74 b/t	b/t = 22	$\frac{4,200}{(b/t)^2}$
		A-18c	Flat plates with both edges supported, bent about X-axis		13.5	- - - -	13.5	h/t = 130	$\frac{230,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-19c	Unstiffened flat webs		8.5	h/t = 19	9.5 - 0.054 h/t	h/t = 79	$\frac{33,000}{(h/t)^2}$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

TABLE 6c.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6063-T6 BUILDING STRUCTURES WELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		I-1c	Any tension member	6.5				
TENSION in extreme fibers of beams, net section		I-2c	Structural shapes, rectangular tubes, built-up members bent about X-axis 	6.5				
		I-3c	Round or oval tubes	7.5				
		I-4c	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	7.5				
BEARING		I-5c	On rivets and bolts	10[b]				
		I-6c	On milled surfaces and pins	7				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION,[a] gross section (Also see Specs. I-8c to I-10c)	I-7c	Columns[a]	6.5	- - - -	6.5	L/r = 88	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7c)	I-8c	Outstanding flanges and legs	6.5	b/t = 4.4	$\frac{13.6}{\sqrt{b/t}}$	b/t = 27	$\frac{1,940}{(b/t)^2}$
		I-9c	Flat plates with both edges supported 	6.5	- - - -	6.5	b/t = 64	$\frac{19,200}{(b/t)^2}$
		I-10c	Curved plates supported on both edges and walls of round or oval tubes	6.5	R/t = 12	$\frac{12.0}{(R/t)^{1/4}}$	R/t = 135	- - - -

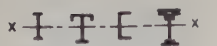
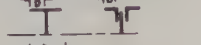
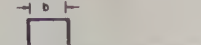
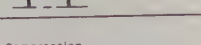
COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION[a] in extreme fibers of beams, gross section (Also see Specs. I-15c to I-18c)	I-11c	Single-web structural shapes and built-up sections bent about X-axis[a]		6.5	- - - -	6.5	L_b/r_y = 107	$\frac{74,000}{(L_b/r_y)^2}$
		I-12c	Round or oval tubes		7.5	R_b/t = 12	$\frac{13.9}{(R_b/t)^{1/4}}$	R_b/t = 125	- - - -
		I-13c	Solid rectangular beams bent about X-axis		7.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 11	$\frac{24.3}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 55	$\frac{9,900}{(d/t)^2 L_b/d}$
		I-14c	Rectangular tubes and box sections[a]		6.5	- - - -	6.5	$\frac{L_b S_c}{I_y}$ = 3080	$\frac{20,000}{L_b S_c / I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11c to I-14c)	I-15c	Flat plates with one edge free and one edge supported		6.5	b/t = 4.8	$\frac{14.2}{\sqrt{b/t}}$	b/t = 31	$\frac{2,500}{(b/t)^2}$
		I-16c	Flat plates with both edges supported		6.5	- - - -	6.5	b/t = 54	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11c to I-14c)	I-17c	Flat plates with compression edge free and tension edge supported, bent about X-axis		7.5	b/t = 8.9	$\frac{19.6}{\sqrt{b/t}}$	b/t = 36	$\frac{4,200}{(b/t)^2}$
		I-18c	Flat plates with both edges supported, bent about X-axis		6.5	- - - -	6.5	h/t = 188	$\frac{230,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-19c	Unstiffened flat webs		4	- - - -	4	h/t = 91	$\frac{33,000}{(h/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification I-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

TABLE 4d.—ALLOWABLE STRESSES IN RIVETED OR BOLTED STRUCTURES OR IN WELDED STRUCTURES AT LOCATIONS FARTHER THAN 1.0 INCH FROM ANY WELD (6063-T5 BUILDING STRUCTURES NONWELDED)

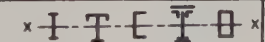
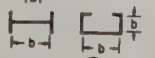
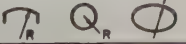
Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		A-1d	Any tension member	9.5				
TENSION in extreme fibers of beams, net section		A-2d	Structural shapes, rectangular tubes, built-up members bent about X-axis	9.5				
		A-3d	Round or oval tubes	11				
		A-4d	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	13.5				
BEARING		A-5d	On rivets and bolts	15[a]				
		A-6d	On milled surfaces and pins	10				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION, gross section (Also see Specs. A-8d to A-10d)	A-7d	Columns	8.5	L/r = 13	9.0 - 0.039 L/r	L/r = 100	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. A-7d)	A-8d	Outstanding flanges and legs	8.5	b/t = 6.8	10.2 - 0.25 b/t	b/t = 19	$\frac{1,940}{(b/t)^2}$
		A-9d	Flat plates with both edges supported	8.5	b/t = 22	10.2 - 0.079 b/t	b/t = 58	$\frac{19,200}{(b/t)^2}$
		A-10d	Curved plates supported on both edges and walls of round or oval tubes	8.5	R/t = 12	9.2 - 0.198 $\sqrt{R/t}$	R/t = 200	- - - -

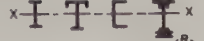
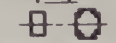
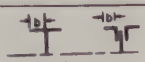
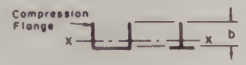
COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION in extreme fibers of beams, gross section (Also see Specs. A-15d to A-18d)	A-11d	Single-web structural shapes and built-up sections bent about X-axis		8.5	L_b/r_y = 16	9.0 - 0.032 L_b/r_y	L_b/r_y = 120	$\frac{74,000}{(L_b/r_y)^2}$
		A-12d	Round or oval tubes		11	R_b/t = 9.4	11.3 - 0.032 R_b/t	R_b/t = 140	- - - -
		A-13d	Solid rectangular beams bent about X-axis		13.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 8.8	15.6 - 0.24 $\frac{d}{t}\sqrt{\frac{L_b}{d}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}}$ = 44	$\frac{9,900}{(d/t)^2 L_b/d}$
		A-14d	Rectangular tubes and box sections		8.5	$\frac{L_b S_c}{I_y}$ = 65	9.0 - 0.062 $\sqrt{\frac{L_b S_c}{I_y}}$	$\frac{L_b S_c}{I_y}$ = 3920	$\frac{20,000}{L_b S_c / I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. A-11d to A-14d)	A-15d	Flat plates with one edge free and one edge supported		8.5	b/t = 7.7	10.2 - 0.22 b/t	b/t = 22	$\frac{2,500}{(b/t)^2}$
		A-16d	Flat plates with both edges supported		8.5	b/t = 22	10.2 - 0.079 b/t	b/t = 58	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. A-11d to A-14d)	A-17d	Flat plates with compression edge free and tension edge supported, bent about X-axis		13.5	b/t = 5.7	15.6 - 0.37 b/t	b/t = 28	$\frac{4,200}{(b/t)^2}$
		A-18d	Flat plates with both edges supported, bent about X-axis		8.5	- - - -	8.5	h/t = 164	$\frac{230,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		A-19d	Unstiffened flat webs		5.5	h/t = 15	5.9 - 0.027 h/t	h/t = 103	$\frac{33,000}{(h/t)^2}$

(a) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or more. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter)

TABLE 3D

TABLE 6d.—ALLOWABLE STRESSES ON SECTIONS WITHIN 1.0 INCH OF A WELD (6063-T5 BUILDING STRUCTURES WELDED)

Type of Stress		Specification No.	Type of Member or Component	Allowable Stress, ksi				
TENSION, axial, net section		I-1d	Any tension member	6.5				
TENSION in extreme fibers of beams, net section		I-2d	Structural shapes, rectangular tubes, built-up members bent about X-axis 	6.5				
		I-3d	Round or oval tubes	7.5				
		I-4d	Rectangular bars and plates, and outstanding flanges of shapes bent about Y-axis	7.5				
BEARING		I-5d	On rivets and bolts	10[b]				
		I-6d	On milled surfaces and pins	7				
				Allowable Stress for Slenderness Less Than S_1, ksi	Slenderness Limit, S_1	Allowable Stress for Slenderness Between S_1 and S_2 ksi	Slenderness Limit, S_2	Allowable Stress for Slenderness Greater Than S_2, ksi
COMPRESSION in Columns Subjected to Axial Load, Gross Section	COMPRESSION,[a] gross section (Also see Specs. I-8d to I-10d)	I-7d	Columns[a]	6.5	L/r = 64	9.0 - 0.039 L/r	L/r = 100	$\frac{51,000}{(L/r)^2}$
	COMPRESSION in components of columns (Also see Spec. I-7d	I-8d	Outstanding flanges and legs	6.5	b/t = 4.4	$\frac{13.6}{\sqrt{b/t}}$	b/t = 27	$\frac{1,940}{(b/t)^2}$
		I-9d	Flat plates with both edges supported 	6.5	b/t = 47	10.2 - 0.079 b/t	b/t = 58	$\frac{19,200}{(b/t)^2}$
		I-10d	Curved plates supported on both edges and walls of round or oval tubes 	6.5	R/t = 12	$\frac{12.0}{(R/t)^{1/4}}$	R/t = 125	- - - -

COMPRESSION in Members Subjected to Bending, Gross Section	COMPRESSION[a] in extreme fibers of beams, gross section (Also see Specs. I-15d to I-18d)	I-11d	Single-web structural shapes and built-up sections bent about X-axis[a]		6.5	$L_b/r_y = 78$	$9.0 - 0.032\ L_b/r_y$	$L_b/r_y = 120$	$\frac{74,000}{(L_b/r_y)^2}$
		I-12d	Round or oval tubes		7.5	$R_b/t = 12$	$\frac{13.9}{(R_b/t)^{1/4}}$	$R_b/t = 125$	- - - -
		I-13d	Solid rectangular beams bent about X-axis		7.5	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 11$	$\frac{24.3}{[(d/t)^2 L_b/d]^{1/4}}$	$\frac{d}{t}\sqrt{\frac{L_b}{d}} = 55$	$\frac{9,900}{(d/t)^2\ L_b/d}$
		I-14d	Rectangular tubes and box sections[a]		8.5	$\frac{L_b S_c}{I_y} = 1620$	$9.0 - 0.002\sqrt{\frac{L_b S_c}{I_y}}$	$\frac{L_b S_c}{I_y} = 3920$	$\frac{20,000}{L_b S_c / I_y}$
	COMPRESSION in components of beams, where component is under uniform compression (Also see Specs. I-11d to I-14d)	I-15d	Flat plates with one edge free and one edge supported		6.5	$b/t = 4.8$	$\frac{14.2}{\sqrt{b/t}}$	$b/t = 31$	$\frac{2,500}{(b/t)^2}$
		I-16d	Flat plates with both edges supported		6.5	$b/t = 47$	$10.2 - 0.079\ b/t$	$b/t = 58$	$\frac{19,200}{(b/t)^2}$
	COMPRESSION in components of beams where component is under bending in its own plane, (Also see Specs. I-11d to I-14d)	I-17d	Flat plates with compression edge free and tension edge supported, bent about X-axis		7.5	$b/t = 8.9$	$\frac{19.6}{\sqrt{b/t}}$	$b/t = 36$	$\frac{4,200}{(b/t)^2}$
		I-18d	Flat plates with both edges supported, bent about X-axis		6.5	- - - -	6.5	$h/t = 188$	$\frac{230,000}{(h/t)^2}$
SHEAR in webs of beams, and also in members subjected to torsion, gross section		I-19d	Unstiffened flat webs		4	$h/t = 70$	$5.9 - 0.027\ h/t$	$h/t = 103$	$\frac{33,000}{(h/t)^2}$

(a) The allowable stresses for columns, single web beams and rectangular tubes and box sections apply to members supported at both ends and welded at the ends only. See Specification I-26 for allowable stresses in these members with welds at locations other than the ends and in cantilever columns and beams.

(b) This value applies for a ratio of edge distance to rivet or bolt diameter of 2 or greater. For smaller ratios, multiply this allowable stress by the ratio, (edge distance)/(twice the rivet or bolt diameter).

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